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A Design Guideline and Evaluation Framework to Determine the Relative Safety of In-Vehicle Intelligent Transportation Systems for Older Drivers

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Transportation Development Centre
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Cognitive Ergonomics Research Laboratory
Department of Psychology
THE UNIVERSITY OF CALGARY

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J. K. Caird, J. S. Chugh, S. Wilcox, and R. E. Dewar
Cognitive Ergonomics Research Laboratory
Department of Psychology
THE UNIVERSITY OF CALGARY

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16. Abstract

The purpose of this project was to develop a design guideline and evaluation framework that can be used to evaluate intelligent transportation system (ITS) applications for older drivers. A number of topics are reviewed that contribute to understanding older drivers; they include transportation ergonomics, driver fatalities and injuries, visual and attentional limitations, compensentory behaviour, and technology usage. The specific ITS technology examined is vision enhancement systems (VES), which have the potential to assist drivers at night to see roadway markings, fixed objects, and pedestrians. A state-of-the-art human factors review of infrared (IVES) and ultraviolet (UVES) vision enhancement systems is provided. In addition, guidelines that apply to the development of VES and designing for older drivers are listed. Also discussed are the contribution of human factors design guidelines and evaluation methods and measures for determining the relative safety of in-vehicle applications.

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16. Résumé

Le but de ce projet était la mise au point de lignes directrices de conception et d'un cadre d'évaluation visant les applications des systèmes de transports intelligents (STI) destinées aux conducteurs âgés. Dans un premier temps, la question des personnes âgées et de la conduite automobile est examinée sous diverses perspectives, dont l'ergonomie dans les transports, les données sur les conducteurs âgés tués ou blessés, les limites de vision et d'attention, les comportements compensatoires et l'utilisation de la technologie. L'étude porte sur une technologie STI particulière, soit les systèmes d'aide à la vision (VES, pour *Vision Enhancement Systems*), qui peuvent aider les conducteurs à mieux voir les marquages de la chaussée, les objets fixes et le piétons la nuit. Le rapport propose une revue de l'état de la technique des systèmes infrarouges (IVES, pour *Infrared Vision Enhancement Systems*) et ultraviolets (UVES, pour *Ultraviolet Vision Enhancement Systems*) d'aide à la vision, sous l'angle des facteurs humains. Il énonce en outre des lignes directrices s'appliquant au développement des VES et à l'adaptation de ces techniques aux conducteurs âgés. On y examine également l'apport que peuvent représenter des critères de conception et des méthodes et mesures d'évaluation fondés sur des principes d'ergonomie pour déterminer la sûreté relative d'applications embarquées.

17. Mots clés
Conducteurs âgés, systèmes de transports intelligents (STI), méthodologie d'évaluation des STI, lignes directrices de conception, sécurité du conducteur, systèmes d'aide à la vision (VES), attention du conducteur, temps de perception-réaction, erreur du conducteur, facilité d'emploi

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EXECUTIVE SUMMARY

The aim of ITS Canada is to "improve the efficiency, safety, and effectiveness of Canadian transportation systems" (*ITS Canada Review: Overview of Results*, 1996, p. 2). Although these are admirable goals, the true impact of intelligent transportation systems (ITS) technology on safety and user performance is not completely understood nor easily predicted. In addition, the economic and political forces that will bring ITS products to the Canadian marketplace may not necessarily be concerned with the safety of the driving public. Products that enter the transportation system should be tested to determine whether the safety of drivers is compromised (Oxley, 1996). "In light of the rapidly increasing number of seniors over 65, [ITS] systems should be designed to accommodate their needs as a matter of practice (i.e. inclusive design), and not on an exclusive basis." (Chandan, 1993, p. 23). Ultimately, to the extent that in-vehicle ITS applications are found safe and effective, drivers and the public at large will not be put at risk. However, if these systems are applied without consideration for those who experience loss due to aging, safety will undoubtedly be compromised. ITS products, if they are to be beneficial, must accommodate the capacities of older drivers and the safety needs of all drivers.

In an overview of automotive ergonomics, the driving task and the requirements for safe operation of a motor vehicle are outlined. The concept of the "design driver" (the typical individual for whom one should be designing) is discussed. An examination of the types of accidents most common among older drivers and the possible responses of older drivers to new in-vehicle ITS technology are also presented.

Any discussion of the impact of new technology on safety must determine what is meant by "safe". The issues include the definition of the term and what changes in the level of safety can be expected (or tolerated, if there is a reduction in safety) when new devices are introduced or "improvements" are made in the transportation system. In an effort to examine consensus on the definition of "safe," 24 international traffic safety experts were asked to define "safe" as it related to driving. While no single definition emerged, the most common elements were (reduction in) accident rate and the need to measure driver visual information processing, attention, and errors.

The design guideline and evaluation framework are applied to the ITS application of vision enhancement systems (VES), which have shown considerable promise for aiding older drivers. The purpose of an evaluation framework of analytic and empirical methodologies is to identify viable techniques and measures that can be used to evaluate ITS applications. The basis of the evaluation framework was derived from a review of literature on ITS interfaces done by research groups in Canada, the U.S., Europe, and Japan. In particular, research that dealt with older drivers, human factors design guidelines, and evaluation methods was analysed in depth. Within the evaluation framework, factors that are somewhat unique to Canada, such as prolonged driving, extensive rural roads, and winter weather, were also considered. The guideline and

evaluation framework will serve as a useful guide for designers, ergonomists, manufacturers, and researchers who wish to determine the relative safety of ITS products before they enter the Canadian transportation system.

Existing methods and guidelines cannot determine whether an ITS product is absolutely safe, because driver behaviour compensation and the long-term interaction of technology on driver skill and knowledge are poorly understood (Green, 1995; OECD, 1990).
A variety of new measures and methods will be required before ITS applications can be assessed for safety prior to entering the transportation system.

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ITS Canada a pour mandat d'améliorer l'efficience, la sûreté et l'efficacité des systèmes de transports canadiens (*ITS Canada Review: Overview of Results*, 1996). Il s'agit là d'objectifs louables, certes, mais l'impact réel des technologies STI (systèmes de transports intelligents) sur la sécurité et la performance des utilisateurs demeure difficile à cerner et à prévoir. De plus, pour les forces économiques et politiques suceptibles de lancer les produits STI sur le marché canadien, la sécurité des conducteurs n'est pas nécessairement une préoccupation majeure. D'où la nécessité de soumettre les produits STI à des essais avant leur intégration au système de transport, afin de garantir qu'ils ne mettent pas la sécurité des conducteurs en danger (Oxley, 1996). Compte tenu du nombre croissant de personnes âgées de plus de 65 ans dans la population, les systèmes STI devraient être conçus pour répondre d'emblée aux besoins des personnes âgées et, par la force des choses, à ceux de l'ensemble des usagers (c.-à-d. respecter des règles de conception «universelle») (Chandan, 1993). En bout de ligne, dans la mesure où les applications STI embarquées seront reconnues comme sûres et efficaces, elles ne représenteront pas de risque ni pour les conducteurs ni pour le public en général. Mais si des systèmes STI étaient implantés sans que soient prises en compte les pertes de capacité dues au vieillissement, la sécurité serait sans doute compromise. Pour être avantageux, les produits STI doivent être adaptés aux capacités des conducteurs âgés et aux besoins de sécurité de tous les conducteurs.

Un survol des aspects ergonomiques du transport automobile met en relief la tâche de conduite et les exigences auxquelles répondre pour garantir une conduire sûre. On y aborde le concept de «conducteur de référence» (la personne-type en fonction de laquelle un véhicule devrait être conçu). Sont également examinés les types d'accidents les plus fréquents chez les conducteurs âgés et les réactions possibles des conducteurs âgés à une nouvelle technologie STI embarquée.

Avant d'examiner l'effet d'une nouvelle technologie sur la sécurité, il importe de définir ce que l'on entend par «sûr». Il s'agit, bien sûr, de définir le terme, mais aussi à quel degré d'amélioration de la sécurité il y a lieu de s'attendre (ou quel degré de détérioration il est permis de tolérer, le cas échéant), du fait de la mise en service de nouveaux dispositifs ou de «perfectionnements» dans le système de transport. Dans le but de mesurer le consensus concernant la définition du mot «sûr», les chercheurs ont demandé à 24 experts internationaux de la sécurité dans les transports de définir ce mot, par rapport à la conduite automobile. Même si aucune définition commune n'est ressortie, les idées qui revenaient le plus fréquemment avaient trait au (besoin de réduire le) taux d'accidents et à la nécessité d'évaluer les conducteurs aux chapitres du traitement de l'information visuelle, de l'attention et des erreurs.

Les lignes directrices de conception et le cadre d'évaluation définis ont été appliqués aux dispositifs STI d'aide à la vision (VES), qui se sont révélés très prometteurs pour les

conducteurs âgés. L'objet d'un cadre d'évaluation de méthodologies analytiques et empiriques est de préciser des méthodes et des instruments de mesures efficaces pour évaluer des applications STI. Le fondement du cadre d'évaluation a été tiré d'une recherche documentaire sur les interfaces STI menée par des groupes de recherche au Canada, aux États-Unis, en Europe et au Japon. Les recherches portant plus particulièrement sur les conducteurs âgés, les critères de conception ergonomique et les méthodes d'évaluation ont été analysées en profondeur. Le cadre d'évaluation prend également en compte certains facteurs propres à l'environnement de conduite canadien, comme les heures de conduite prolongées, le réseau étendu de routes rurales et les conditions de conduite hivernales. Les critères de conception et le cadre d'évaluation serviront de guide pratique pour les concepteurs, les ergonomes, les fabricants et les chercheurs qui désirent déterminer la sécurité relative de produits STI avant qu'ils soient intégrés au système de transport canadien.

Les méthodes et lignes directrices existantes ne permettent pas de déterminer la sûreté absolue d'un produit STI, car les comportements compensatoires des conducteurs et les effets à long terme de la technologie sur les habiletés et les connaissances des conducteurs, et réciproquement, demeurent mal compris (Green, 1995; OCDE, 1990). Il faudra donc mettre en place de nouvelles mesures et méthodes afin que la sûreté des applications STI puisse être évaluée avant leur intégration au système de transport.

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GLOSSARY

ACC	Adaptive Cruise Control
ADIS	Advanced Driver Information System
AI	Artificial Intelligence
ATIS	Advanced Traveler Information System
AV	Advanced Vehicle
AVCS	Automatic Vehicle Control Systems
AVL	Automotive Vehicle Locator
CAD	Computer-Aided Dispatch
CAS	Collision Avoidance System
CVO	Commercial Vehicle Operations
CWS	Collision Warning System
EMS	Emergency Medical System
FARS	Fatality Accident Reporting System
GIDS	Generic Information Driver Support
GPS	Global Positioning System
HCI	Human-Computer Interaction
HF	Human Factors
HMD	Helmet/Head Mounted Display
HUD	Head-Up Displays
ICC	Intelligent Cruise Control
IMSIS	In-Vehicle Motorist Services Information Systems
ISIS	In-Vehicle Signing Information Systems
ITS	Intelligent Transportation Systems
IVES	Infrared Vision Enhancement Systems
IVSAWS	In-Vehicle Safety Advisory and Warning Systems
OBC	On-Board Computing
RTI	Road Transport Informatics
UVES	Ultraviolet Vision Enhancement Systems
VES	Vision Enhancement Systems
VICS	Vehicle Information and Control System

Organizations

DRIVE/DRIVE II	
EDDIT	Elderly and Disabled Drivers Information Telematics
FHWA	Federal Highway Administration
HIDO	Highway Industry Development Organization
ISO	International Organization for Standardization
ITS AMERICA	Intelligent Transportation Systems of America
IVHSA	Intelligent Vehicle Highway Society of America
NHTSA	National Highway Traffic Safety Administration
OECD	Organization for Economic Cooperation and Development
MTO	Ministry of Transportation of Ontario
PROMETHEUS	Program for European Traffic with Highest Efficiency and Unprecedented Safety
SAE	Society of Automotive Engineers
TC	Transport Canada
TDC	Transportation Development Centre
TRB	Transportation Research Board
UMTRI	University of Michigan Transportation Research Institute

1.0 INTRODUCTION

Intelligent Transportation Systems (ITS). The societal goals of intelligent transportation systems are to decrease accidents, congestion, and pollution. These are hardly new social problems, although each is likely to increase in the future (Evans, 1991; Gibbs, 1997; Ranney and Simmons, 1993). Interestingly, greater levels of congestion or slowed, impeded travel reduces the severity of accidents and thus increases safety. A number of domains that have a bearing on the development of ITS applications are considered. Many ITS technology initiatives are the product of advances in telecommunications, automotive electronics, and computing. A wide variety of new driver information systems are part of these initiatives in the U.S., Europe, Japan, and Australia. For example, driver information systems include: in-vehicle telephony, laptop and personnel digital assistants (PDAs), on-road hazard warnings, smart signs, congestion and vehicle system monitoring, navigation, and tourist and emergency services. New applications, which are hybrids of computing, communications, and global positioning systems (GPS), are emerging routinely.

A number of ITS in-vehicle applications are in widespread use today. For example, navigation systems in Japan have achieved an approximate 40% market penetration. This success is not matched in other countries and is due, in part, to the street and housing number conventions that are organized by towns and agricultural area. Because of this, it is very difficult to locate particular buildings unless local residents are asked. Navigation technology has partially solved this practical problem. Similarly, intelligent cruise control (ICC) appears to be on the verge of becoming a viable commercial product (Sayer et al., 1997). In Canada, Highway 407, north of Toronto, which is an automated toll road, has been exemplified as a model of provincial and federal funding cooperation (Crook, 1997). Thus, ITS successes are becoming evident and as the market matures and products are refined the number of viable products will increase.

ITS and Safety. ITS display technologies have the potential to increase or decrease the safety within the Canadian transportation system. For the driver and society, the introduction of new technologies can have both subtle and dramatic effects that are difficult to predict (Evans, 1991; Michon, 1985; OECD, 1990; Wiener, 1994). While the number of new driver information systems continues to grow, the value and functional meaning of new driver information has yet to be determined[1]. To date, it has been the application of technology,

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[1] Driver information systems are described by an array of acronyms such as Advanced Driver Information Systems (ADIS), Advanced Traveler Information Systems (ATIS), and Generic Information Driver Support (GIDS). ITS and institutional acronyms used in this report can be found in the Glossary on page xiii.

rather than driver information needs, that has predominately captured the marketplace initiatives of many ITS developers. For example, the proliferation of driver information systems such as ADIS, ATIS, and GIDS has the potential to overwhelm and/or distract the driver (e.g., Hancock and Caird, 1992; Ranney and Simmons, 1993). The purpose of ITS in-vehicle products is to aid the driver. The bottom line is that ITS applications should increase mobility, but not compromise safety (Suen and Mitchell, 1997).

Human Factors. "Human factors in transportation has primarily considered the relative immediate fit between the transportation system and the user" (Waller, 1997, p. 2). For example, if the task of the older driver can be re-engineered, all of society will benefit (Waller, 1991). "Human factors applied to ITS is about making in-vehicle display devices safe and efficient" (Mast, 1995). Advocacy of user-centered design principles and efforts to reduce loss of life and capability also comprise the application of human factors knowledge and methods to ITS. As ITS is still in its infancy, and maturing rapidly, there is a pressing need to generate adequate human factors knowledge on which to build useful and usable ITS products. "[T]he rapid development of in-vehicle technology is likely to produce situations where drivers are inundated with information from non-integrated systems. Regulations about what types and combinations of systems are acceptable on safety grounds may well be required" (Smiley, 1995, p. 7). Human factors methods and measures should seek to address this and related problems.

Older Drivers. The number of licensed older drivers in the U.S. and Canada is likely to nearly double for males and triple for women in the next twenty-five years (Eberhard, 1996). Similarly, demographic changes will contribute to similar increases in licensed older drivers in Canada. Traffic fatalities, when adjusted for reductions in annual mileage, is higher for older drivers than for other age categories except the youngest (Cerelli, 1989). It is commonly understood that visual, attentive, memory, and perceptual-motor capabilities differentially decline with age. Impairments may also result from medical conditions such as eye disease and various forms of dementia. The degree that these declines necessarily lead to vehicle accidents is not well understood. For example, attempts to find relationships between single and multiple abilities and vehicle accidents have achieved minimal success. This may be, in part, due to the adaptations that older drivers make to their declining abilities.

Older Drivers and ITS. Older drivers may benefit from the array of ITS technologies that are being developed if the technologies are designed using human factors principles (Mitchell and Suen, 1997; Perel, 1998). ITS should not create any barriers to mobility for older drivers (Mitchell, 1997a). A number of ITS applications, such as navigation, emergency vehicle location, and collision warning systems, appear to be important ITS applications for older drivers. Vision enhancement systems (VES) have the potential to benefit older drivers. VES have the potential to restore the loss of visual capability experienced by many elderly drivers (Suen and Mitchell, 1997). However, this potential can only be realized if VES and other ITS products fulfill an important function, can be easily used, and do not reduce safety. Specifically, VES may benefit those with reduced visual acuity at night, seniors, and some people with poor vision (Suen and Mitchell, 1997).

1.1 Project Objectives

- To identify and cite the relevant human factors guidelines that support design requirements that will increase the safety of ITS devices for older drivers.

- To identify the most promising methodologies and techniques from transportation ergonomics, human error, gerontology, cognitive engineering, human-computer interaction, and artificial intelligence, that will address the fit between the diminished capabilities of older drivers and the demands of ITS in-vehicle applications.

- To develop a design guideline and evaluation framework for in-vehicle ITS interfaces for older drivers. The evaluation framework is illustrated using vision enhancement systems.

1.2 Project Benefits

- Ultimately, drivers with safe and effective ITS interfaces will have fewer accidents. Thus, reductions in vehicle damage, injury, and loss of life, are sought.

- To the degree that in-vehicle ITS applications are optimized without compromising safety, older drivers' personal mobility is likely to be enhanced.

- Given the evolution and fiscal emphasis of ITS products by ITS America and Canada and by the DRIVE and PROMETHEUS programs in Europe, Transport Canada has the opportunity to cooperatively share transportation ergonomics knowledge.

- Introduction of ITS products into Canada is likely to be incremental. Knowledge about how to evaluate safety critical applications prior to introduction is essential.

Canadian Involvement in ITS. These objectives and project benefits are aligned with ITS Canada (Johnson and Harmelink, 1995: 3.1.5 Accessibility for Elderly and Disabled Travelers; 3.1.9, Driver Safety and Crash Avoidance Concerns; 3.2.6, Human Factors Research, and 3.3.3, International Standards) recommendations for Canada's involvement in Working Group 13 (WG 13) of the International Organization for Standardization (ISO) Technical Committee (TC 22) on Road Vehicles (see, e.g., Smiley, 1995; Parkes, 1997), and Transport Canada's Ergonomics Group (see Noy, 1997). The proposed research is also aligned with the Transportation Development Centre's mandate and research priorities (Suen and Mitchell, 1997, p. 9). For example, Suen and Mitchell call for international cooperation to develop suitable guidelines for ITS products for the elderly and disabled so that the products are safe and easy to use.

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2.0 PROJECT APPROACH

A variety of analytic activities were engaged in to produce the deliverables of this project. These are represented in Figure 2.1. Processes appear on the left and products on the right. Each process is briefly described.

Literature from cognition, human-computer interaction (HCI), transportation ergonomics, human factors, older driver road vehicle accidents, elderly driver performance, ITS guidelines (collision warnings, vision enhancement, collision avoidance, and intelligent cruise control) from the University of Calgary's library, the University of Michigan's Transportation Research Institute library, interlibrary loan, and Web-based information was queried. A large database of these references was created at the conclusion of this process (Caird et al., 1998). In addition, a Web page with transportation human factors, older driver information and ITS product links was created.

http://www.acs.ucalgary.ca/~erg/its/tc.htm

Literature specific to the evaluation framework, older drivers, visual enhancement systems (VES), ITS guidelines, and evaluation methods was read and synthesized. The relative strengths and weaknesses of each citation were weighed using author reputation and peer review as selection criteria. The automotive ergonomics (Section 3), the older driver (Section 4), guidelines (Section 6), and evaluation (Section 7) sections were written according to these criteria. Section 5, the vision enhancement system section, was based on available literature, which varied somewhat in quality.

Four ITS driver applications were initially considered for analysis in the framework; namely, vision enhancement systems (VES), emergency alert or Mayday systems, intelligent cruise control (ICC), and collision avoidance systems (CAS). Each is briefly described.

Vision Enhancement Systems (VES). Infrared vision enhancement systems (IVES) use a sensor-display system to represent thermal differences between an object and its background, such as pedestrians on the road. Ultraviolet vision enhancement systems (UVES) are designed to aid drivers in the detection of driving-related environment features such as lane markings at night and in adverse conditions (e.g., rain, fog, and snow). A comprehensive literature review of VES can be found in Section 5.

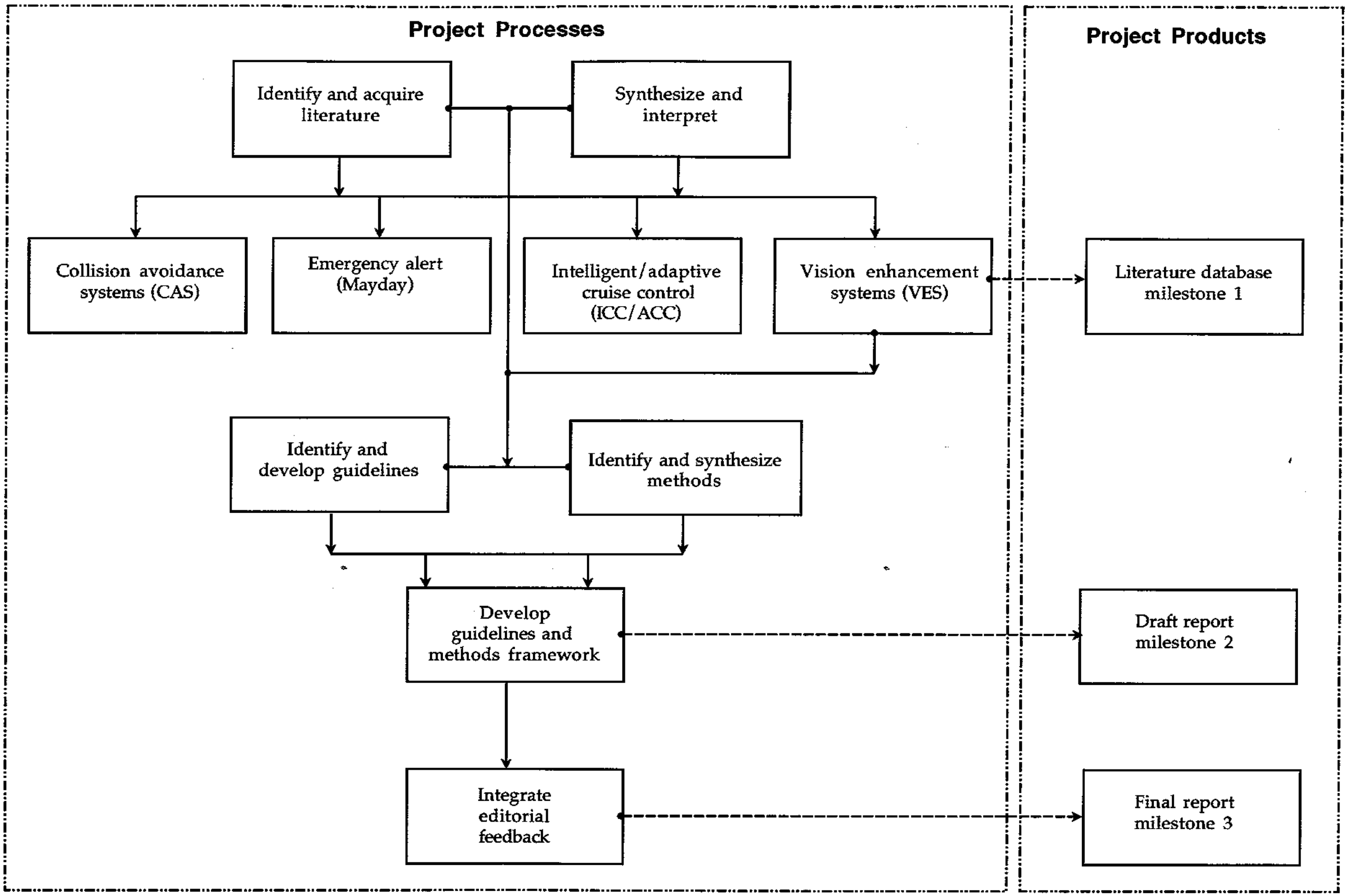

Figure 2.1. Project methodology. See text for description.

Emergency Alert or Mayday Systems. An emergency alert or Mayday system transmits the status and/or location of a vehicle that is malfunctioning or has had an accident to a dispatch centre (see, e.g., Oxley et al., 1995). Mayday systems have the potential to speed the delivery of emergency medical services in rural areas. The National Highway Transportation Safety Administration (NHTSA) noted that 93% more rural accidents result in deaths than do urban crashes (NHTSA, 1996). The timely delivery of emergency medical services has been identified as one of the primary reasons that fatal traffic accidents have declined in industrial nations over the past forty years (Evans, 1991). If Mayday systems can reduce emergency response service (EMS) response time to older drivers, accidents—especially in rural areas—it will become an important ITS application. Once in an accident, an older driver is three times more likely to die than a younger driver (Evans, 1988). Thus, rapid delivery of emergency medicine is likely to benefit older drivers.

Intelligent Cruise Control (ICC) and Adaptive Cruise Control (ACC). The purpose of ICC is to increase driver comfort by adapting conventional cruise control, through sensor feedback loops and/or algorithmic tailoring, vehicle velocity to changes in headway (see, e.g., Francher, et al., 1997). A large-scale field trial in the U.S. is under way which has included older drivers as a test group (see, e.g., Sayer, et al., 1997). Initial results have been favourable. ICC will likely become a viable consumer product within the next five years.

Collision Avoidance Systems. Collision avoidance systems (CAS) convey to a driver the direction and severity of a collision threat depending on rapid changes in the traffic environment. Given the over-representation of the elderly in vehicle accidents, the application of CAS appears promising. The design constraints of information timing and semantics on each CAS type are quite challenging (see, e.g., Caird, 1995; Dingus, et al., 1998; Tijerena, 1995).

After some deliberation over these four ITS applications, the Transportation Development Centre (TDC) decided that the focus of this report would be vision enhancement systems (VES), because:

- VES show particular promise to restore older driver mobility in the face of vision losses. Driving is overwhelmingly visual (Sivak, 1996), and older drivers loose their visual capability from disease and natural degenerative processes, which increase with age.

- VES have the potential to increase mobility and safety when weather and nighttime driving conditions are faced by drivers. In Canada, fog, snow, and rain are significant environmental factors that contribute to accident occurrence. Similarly, many roads in Canada are unlit and given the long winters, extended nighttime driving is required of many drivers.

- Throughout the technical reports and conference proceedings papers that were reviewed, with few exceptions, the consensus was that VES have a high potential as an aid for older drivers.

- Research and development within various automobile manufacturers (e.g., Volvo, Saab, GM, Nissan, Jaguar, BMW, Renault) indicate that VES have been targeted as potential products (also see Mitchell, 1997a, 1997b).

A large body of guidelines from FHWA, NHTSA, UMTRI, EDDIT, and CHI were put together to form Appendix A: ITS Guidelines. A guideline from these sources was listed if it broadly or specifically applied to VES or the visual requirements of older drivers. Guidelines that were considered most relevant to VES are indicated as such. Section 6 discusses a number of issues surrounding the use of these guidelines listed in Appendix A.

Evaluation methods that could be applied to in-vehicle displays—especially for older drivers—are reviewed (Section 7). While many methods from transportation ergonomics, such as driving simulation and field trials, are accepted as common practice, other approaches from AI, CHI, and process control are also introduced. A synthesis of guidelines and methods forms the evaluation framework. Prescriptions and issues for its use are described (see Sections 7 and 8).

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3.0 AUTOMOTIVE ERGONOMICS

Transportation ergonomics can address many issues that surround the use of ITS applications for older drivers. Ergonomic questions within transportation typically focus on the perceptual, attentional, cognitive, and motor performance limitations that impinge on safe vehicle operation. These capabilities are known to decline differentially with age (see, e.g., Birren and Fisher, 1995; Rabbitt, 1993). In addition, individual differences that dispose certain drivers to higher injury and accident rates provide data on drivers who may benefit from countermeasures (Evans, 1991). The purpose of this section of the report is to review the driving task from the point of view of ergonomics and to apply what is known about elderly drivers to the evaluation of ITS generally, and to one specific system in detail, namely, vision enhancement systems (VES).

3.1 An Overview of Automotive Ergonomics

The importance of understanding the human element in the system can be appreciated from the words of Ogden (1990, p. 41) who states that the road traffic system "... is inherently unstable and is maintained in equilibrium only by the frequent intervention of the human".

The safe and efficient use of the roadway system is influenced by a number of user factors, including physical/physiological (e.g., age, strength), psychological/behavioural (reaction time, emotion) and cognitive (attention, decision making) characteristics. The study of drivers' capabilities and limitations is the realm of ergonomics. The characteristics of road users and their interaction with the other elements of the system—the vehicle, road, and environment—have been the objects of considerable research.

The impact of any modification to a component of the highway transportation system, including drivers (e.g., driver education) on safety is difficult to assess, since accidents (the bottom-line index of safety) are rare events. In addition, a significant proportion of "accidents" go unreported, if there is little property damage and/or injuries are minor. The limitations of accident reporting are well known (Elander et al., 1993; Evans, 1991).

3.2 The Driving Task

Driving a vehicle, except as a novice, becomes overlearned and relatively automatic. Nevertheless, driving is a very complex task, involving a variety of skills, the most important of which are the taking in and processing of information and making quick decisions based on this information. Although a great many models and schematic representations of driving can be found, Wilde's model illustrates the complexity of the task of driving (see Figure 3.1). His cognitive and motivational model of driver behaviour is appealing, because it addresses the three major components of driving (the vehicle, the driver and the roadway/environment), a number of human characteristics, including cognitive states (e.g., perception, memory), current physical and psychological states of the driver, numerous modulating factors (e.g., age, gender, personality), and driver motivation. In addition, it takes into account short-term and long-term decisions and the driver's manipulation of vehicle controls. A central component of Wilde's model is the concept of "tolerated subjective danger", which the driver compares to his/her "subjective estimated danger" and acts according to any discrepancy between these two. Older drivers have been found to display reduced capacity and performance in many of the variables that appear in Wilde's model (also see Section 4.4).

Driving may be viewed as a hierarchy of subtasks on three levels—strategical (e.g., decisions about route and time of day), tactical (e.g., reducing speed in a school zone), and operational (e.g., steering, scanning the roadway)—each requiring specific, but different, skills (Michon, 1985). The greatest time pressure and the greatest consequences of an error exist in the last of these, and least at the strategical level. Older drivers are likely to have difficulty at all levels (Brouwer et al., 1988).

The driving task itself can be broken down into three main elements— control, guidance, and navigation, as outlined in the Positive Guidance approach developed by Alexander and Lunenfeld (1975). Control involves the driver's interaction with the vehicle, in terms of speed and direction (accelerating, braking, steering). Relevant information comes mainly from the vehicle and its displays. Guidance refers to maintaining a safe path and speed and keeping the vehicle in the proper lane on the road. Information comes from roadway alignment, hazards, traffic control devices, and other vehicles and pedestrians using the roadway. Navigation means planning and executing a trip from one location to another. Navigational information comes from indicators such as maps, guide signs, landmarks.

According to Alexander and Lunenfeld, the first of these has the highest priority, in the event of an emergency, while navigation has the lowest. Performance is relatively simple and overlearned at the control level, but information handling is more complex at the other levels.

In a similar vein, driving is a dynamic process, because the scene ahead and the information from it are continually changing as one proceeds along the roadway (see Hills, 1980). At high speeds, the information that the driver needs comes in very quickly. Hence, rapid and accurate information processing is essential to safe driving. The time to respond successfully to any driving situation, such as an emergency, involves four stages: perception (detection and identification), decision, reaction, and response of the vehicle (Olson, 1996).

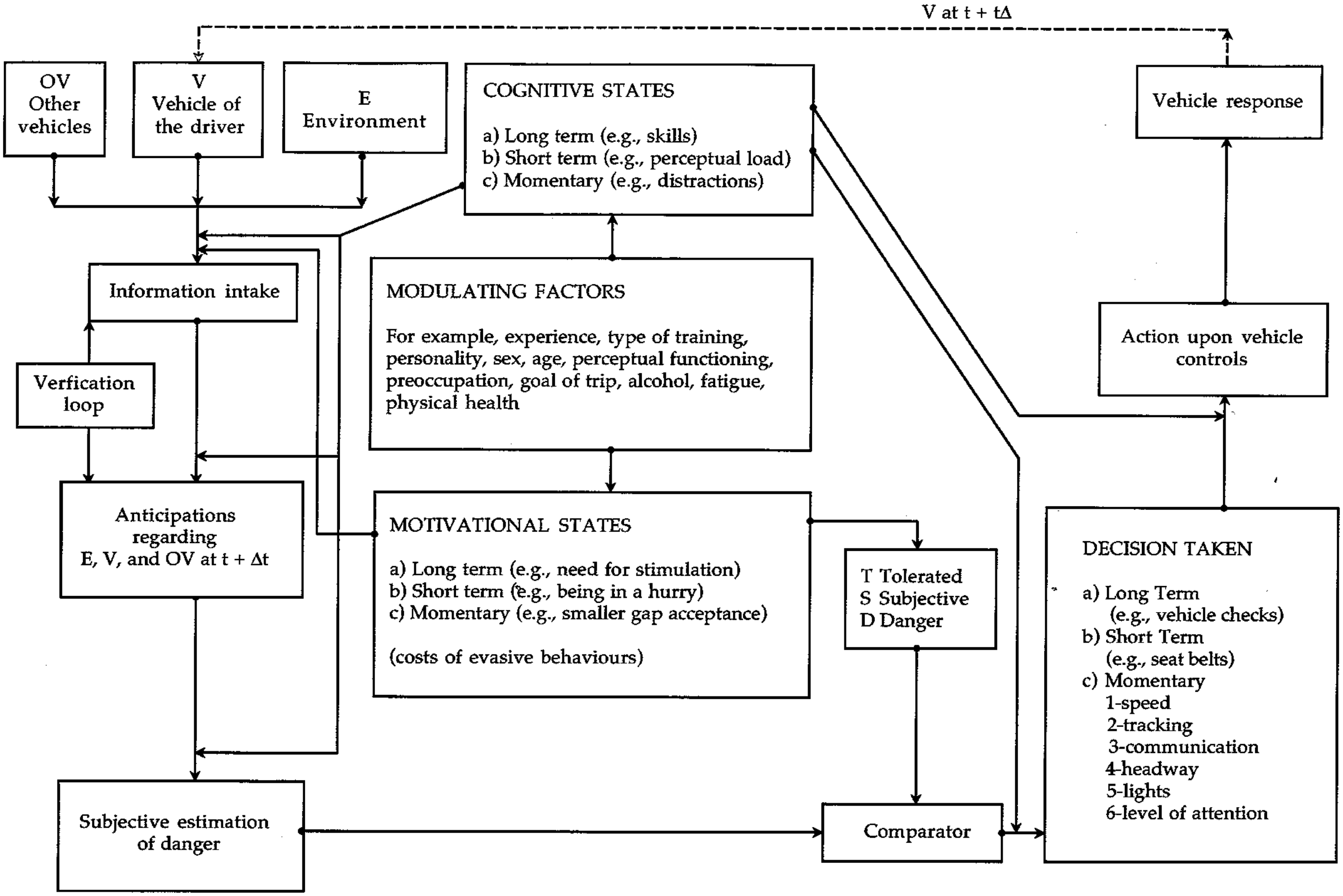

Figure 3.1. A cognitive and motivational model of driver behaviour. Adapted from Wilde, G. J. S. (1976). Social interaction patterns in driver behaviour: An introductory review. *Human Factors, 1*(5), 477–492. Permission to use granted by the author and *Human Factors*.

While discussing the task of driving, it is essential to keep in mind the distinction between driver performance—what the driver can do in terms of perceptual and motor skills, etc.—and driver behaviour—what the driver actually does on the road (Evans, 1991). The former is often evaluated with laboratory tests using standard psychometric measures, driving simulators, etc. However, Evans (1991) suggests that behaviour can only be measured properly on the road in real driving situations. This would appear to be a somewhat biased view, as a good deal can be learned about on-the-road behaviour from laboratory and simulator experiments (see Section 7).

To understand human performance in any person-machine system, an analysis of the task requirements (a "task analysis") is needed. A task may be viewed in terms of:

- the stimulus characteristics of the situation
- behavioural descriptions (what the performer actually does)
- ability requirements (personal abilities and characteristics of the performer)
- behaviour requirements (responses required of the performer to meet some criterion of success) (OECD, 1976).

Task analysis can be divided into two stages: 1) description of the task; 2) analysis of the behaviour involved in the task. The behavioural aspects of the task are central to the development of a complete task analysis.

One of the first systematic efforts to analyze the driving task was undertaken by McKnight and Adams (1970), who determined that there are well over 1000 different components involved. An example of this fine-grained analysis would be overtaking another vehicle, where the components include: search for and interpret relevant signs and lane markings, observe roadway ahead, judge available passing distance and time, accelerate to overtake, complete manoeuvre, and return to original lane. They identified six on-road task categories, namely: basic control (e.g., steering), general driving (surveillance), traffic conditions (passing), roadway characteristics (intersections), environment (weather), and the car (car emergencies). Off-road task categories included pre-trip planning, maintenance, and legal responsibilities.

The two main approaches to driving task analysis involve input-output characteristics (depending on the input to the driver, the performance requirements are derived and driver skills and knowledge are specified), and what is happening between input and output (the human functions, especially information processing, involved in the task). While it can be helpful to break down the driving task into many components, as McKnight and Adams (1970) have done, this detailed analysis of the task may be misleading. The difficulty is that there are no clear beginning or end points between task components. In addition, these components are often interdependent. Hence, it may not be possible or appropriate to deal with individual task components in isolation.

3.3 The Design Driver

A great many human characteristics and individual differences influence the ability of drivers to use the roadway system properly. In order to appreciate these, the concept of the "design driver" needs to be understood (Burg, 1972). This term refers to the range of drivers whose abilities and limitations need to be taken into account in designing roads, vehicles, traffic control devices, road maps, and so forth. It may be considered in terms of the "reasonable worst case". There is no such person as the "average driver" or the typical 85th percentile driver, as any individual will vary with respect to different characteristics and abilities. The driver with very good vision may have average hearing and poor motor coordination. Older drivers exhibit great variability in the skills and characteristics required for driving. Hence, they should be taken as the drivers for whom vehicles, roads, and traffic control devices are designed.

Approximately 40% of all traffic accidents involving human error have as contributory factors difficulties in information processing or perception (Treat et al., 1979). It is generally agreed, but never properly documented (Sivak, 1996) that 90% of the information a driver receives is visual, and the importance of vision is reflected in the emphasis placed on it in driver licensing tests.

It may seem obvious that visual abilities are important, but a large study in California (Henderson and Burg, 1974) failed to find a consistent relationship between most of these abilities and accident rates (also see Schieber, 1994). In fact, it has been found that drivers with very poor vision often have better than average driving records—mainly because they are aware of their problem and compensate by driving with extra care. However, those visual abilities associated with the processing of dynamic information (which is especially important in a task where the operator and objects in the environment are in motion) were correlated with accident rates. The essential abilities include central angular movement, central movement in depth, and dynamic visual acuity.

Under perfect performance, driver output (performance) corresponds with input (demand). However, actual performance under increasing input will increase, then decrease. Drivers are like single-channel processors in this latter case. That is, they cannot properly attend to more than one input at a time, but they do engage in rapid attention switching. Lack of ability to switch attention has been found to be related to accidents among drivers (Lim and Dewar, 1988). The road and vehicle systems should allow drivers to adjust their pace downwards by shedding irrelevant input and tasks. This can be done by providing advance information and meeting driver expectancies, avoiding sudden increases in in-vehicle or extraneous demand, locating traffic control devices where drivers most need the information, and avoiding the need for complex decisions by the driver.

3.4 Behavioural Compensation

The research literature indicates that a number of skills required for driving deteriorate with age. However, many older drivers become aware of their own deficiencies and compensate for them in a number of ways. Perhaps the most obvious are reductions in speed, more cautious behaviour on the road, and less driving under nighttime, bad weather, and heavy traffic conditions. Brouwer et al. (1988) examined older drivers' ability to engage in appropriate compensatory behaviour. These authors assume that driving is a hierarchy of subtasks, on three levels; namely, strategic, tactical, and operational (also see Section 3.2). Older drivers, as compared with their younger counterparts, were found in a laboratory simulator test to be poorer at adapting to the effects of a side wind and less efficient at establishing an optimal speed-accuracy trade-off (two indices of performance at the operational level). As a follow-up to the lab study they matched older drivers' driving ability (as measured by driver examiners) and their scores on tests intended to gauge information processing speed and tactile supervisory control. At the extreme ranges (subjects who were fast at simple information processing and performed well at the tactical level, or who scored low on these two indices), elementary processing speed and supervisory function on the tactical level were found to be predictive of driving performance.

The research on behavioural compensation by drivers in response to improvements in highways or vehicles has been plagued with controversy. Some safety countermeasures, such as the use of studded tires, have been found to produce riskier driver behaviour, while other countermeasures have not. A summary of the literature prior to 1990 by the OECD (1990) concludes that behavioural adaptation occurs for certain vehicle improvements (antilock braking systems, studded tires), but not necessarily for others (daytime running lights, seat belts). Unfortunately, the OECD review of the behavioural compensation literature does not address age differences in regard to vehicle or roadway modifications.

3.5 Defining "Safe"

An issue of concern with the introduction of any technology into the transportation system, especially one as new and different as VES, is safety. The initial enthusiasm about ITS was generated on the basis of the engineering advances that allowed the presentation of such information as vehicle status, lane keeping, and potential collisions both from the front and the sides the vehicle. Little was known about how drivers would respond to, and how well they could use, these new sources of information. A very real concern is the potential for overloading the driver, who already has a good deal of information to process, especially in urban environments and under adverse weather conditions.

The questions that arise from this concern are whether the new ITS devices (e.g., an in-vehicle navigation or collision avoidance systems) are safe, and what constitutes "safe" as it applies to new technology of this type. The issue of "how safe is safe enough?" is to some extent a philosophical question. One could argue that no human activity is 100% safe—there is always at least some risk (to the driver, pedestrian, or cyclist, in the case of the traffic system). It seems reasonable to expect that the introduction of a new technology should be at least as "safe" as was the case before its introduction. A new technology intended to increase traffic safety will not necessarily lead to the desired result of reducing accidents, as can be seen in the earlier discussion of behavioural compensation. In fact, the introduction of new technology may significantly alter the nature of the driving task.

A good deal has been written about risk, the acceptable level of risk that society will tolerate (e.g., Fischhoff et al., 1981), and the individual's tolerance for risk in driving (Wilde, 1982, 1994). It is known that most drivers are not good at estimating risk on the road, and that they tend to rate themselves as somewhat better than the average driver. Little is known, however, about how drivers perceive the risks or benefits (if any) associated with ITS. There is a need to determine how safe these new devices are and how they are used and perceived by drivers, especially older drivers. Fischhoff (1990) indicates that more risk is usually tolerated for well-understood technologies. The extent to which this might apply to ITS is unknown.

With the intent of arriving at a definition of "safe" as applied to driving, a number of international traffic safety experts (mostly human factors researchers) were asked to define "safe" as it relates to driving. The request, sent out by e-mail and fax, elicited responses from 24 people. Several respondents indicated more than one element in their definition (see Table 3.1).

Table 3.1. Definitions of “safe”. Frequencies with which specific elements were mentioned in the definition of "safe".

Accidents/accident rate	11
Errors	6
Mental workload	5
Cost/benefit	4
Attention	3
Eye fixations on road	3
Information processing	3
Task demands	2
Prevent harm	1
Time to collision	1

The replies were quite varied, but a number of themes emerged. Most respondents provided a definition in terms of measures (e.g., eye movements, erratic manoeuvres) that might be used in evaluating in-vehicle systems. About half of the replies indicated that accidents or accident rates are the primary indicators of traffic safety. Likewise, mental workload, task demand, or attention were indicated by about half of the respondents, while six considered driver error to be the main criterion.

The issue of "safe relative to what?" was raised by some people, and the related notion of cost/benefit to society was mentioned by 4 respondents. One concern was that the introduction of new technology into vehicles should at least not lead to more accidents/injuries than at present (see Smiley, 1995).

From this brief survey of selected experts in the area, no strong consensus about what constitutes "safe" as it applies to driving emerged. However, operational definitions most often mentioned involved minimizing accidents, and measuring attention or information processing and driver errors. Definitions incorporating specific skills seem reasonable, but a definition of safe in terms of accident rate is of little help in evaluating a new technology. It is not feasible to introduce a device and then wait to see whether accident rates change. One must determine whether the new device impacts in a positive or negative manner on the skills known to be essential to the driving task.

3.6 Summary

From this brief discussion of basic automotive ergonomics, driving task demands, and performance requirements, it can be seen that the operation of a motor vehicle can be quite challenging, especially under less than optimal conditions. Many of the skills required to operate a vehicle safely are the same ones that deteriorate with age. This is especially the case for information processing abilities. As will be seen in Section 4, older drivers are over-represented in traffic accidents, even though they typically drive less and compensate (modify their driving) more than do younger drivers. The factors that contribute to higher older driver accident rates are often those that reflect diminished capacity and performance associated with the aging process.

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4.0 THE OLDER DRIVER

> *[T]he older driver problem may be one of reduced mobility more than one of reduced safety* (Evans, 1988a, p. 34).

Since the Transportation Research Board's Special Report 218 (1988) on *Transportation in an Aging Society* and NHTSA's *Conference on Research and Development Needed to Improve Safety and Mobility of Older Drivers* (1989), researchers produced papers and reports that have dealt with many of the important issues raised in these meetings (see, e.g., Ball et al., 1993; Dewar et al., 1994; Hakanies-Blomqvist, 1996; Hanowski et al., 1995; Lerner, 1994; Massie et al., 1995; Ponds et al., 1988; Schieber, 1994). Thus, the body of research on the older driver has increased dramatically in the past decade. While the U.S. and Canada share some demographic similarities, such as a large potential increase in the elderly, an increased research emphasis on older drivers did not occur on the same scale in Canada. Therefore, transportation policy must be placed on a solid understanding of existing research that may or may not apply to Canadian drivers and traffic environments.

While a large body of research has been produced on the elderly driver and knowledge has increased significantly, many things about the older driver are still not known. For example, researchers charged to determine what to do about various facets of the "older driver problem" typically review or create new knowledge about travel patterns, the link between vision, perception, attention and accident occurrence, and the effects of aging, drugs, and alcohol on driver performance. Missing from these focused research efforts is a systems perspective on how different levels of analysis contribute to an understanding of how to preserve safety and increase mobility. Levels of analysis in driving might include overall accidents, specific accident typologies, driver behaviour, driver performance, basic processes (i.e., vision, attention, perception, cognition, motor skills) and physiological control and regulation.

The research emphasis on linking basic sensory, attentional, and perceptual processes to accident occurrence can be viewed as an unfortunate excursion in linking levels of analysis, that is, determining the relationships between basic human processes and accidents or driver performance. The basic processes that are engaged while driving are many. How one or several (e.g., divided attention, peripheral vision) might necessarily lead to an accident if modestly deficient, is a very difficult problem. Traffic accidents are singular, very improbable events (see, e.g., Evans, 1991b, Table 13-2, p. 345) that occur because a number of accident precursors happen to co-occur (Treat, 1980). Thus, a many, many to many link must be established to determine a significant relationship. That humans can learn and adapt based on internal and external feedback also reduces the likelihood that such a relationship will be established for a given population sample. For example, driving performance has been linked to peripheral vision and divided attention (Schieber, 1994; Sivak, et al., 1995). Visual acuity, peripheral vision, and aspects of attention are weakly related to older driver accidents (Ball and Owsley, 1991; Parasuramen and Nestor, 1991; Schieber, 1994; Sivak, et al., 1995). Because many-to-one and many-to-many mappings occur between levels of analysis, the research strategy of establishing these links is likely to progress slowly (incrementally) like many other scientific domains. A number of these levels of analysis are addressed here. Specifically, overall accident frequencies, older driver accident typologies, age-related declines in abilities, older driver behaviour compensation, and older driver response to new technology are reviewed.

4.1 Canadian Population Demographics

An accurate description of a problem precedes solutions to it. Numerous studies have attempted to determine whether older drivers have higher accident frequencies than other segments of the driver population (Cerrelli, 1989; Evans, 1988a; Massie, Cambell, and Williams, 1995). If the frequency of fatalities and injuries for older drivers exceeds the frequencies for other age categories, it represents a need to intervene to reduce the social cost. While the older U.S. driver accident rates have been described, data for the older Canadian driver have not. Thus, we attempt to quantitatively describe Canadian older driver accident statistics. Older drivers are defined here as those over the age of 65.

Five principal questions drove our analysis of available Canadian accident data. These were:

- Is the Canadian population, especially those over the age of 65, expected to increase?
- Over time, are accidents decreasing in Canada?
- Do those over the age of 65 have more accidents than other age groups?
- Are there gender differences in accident frequencies?
- Will the percentage of older persons who are licensed increase in the future?

The population of Canada for all age groups will increase from 1996 to 2041 (see Figure 4.1). Overall, a 43 percent increase is estimated in Canadian population over this trending period (George et al., 1994; Statistics Canada, 1997).

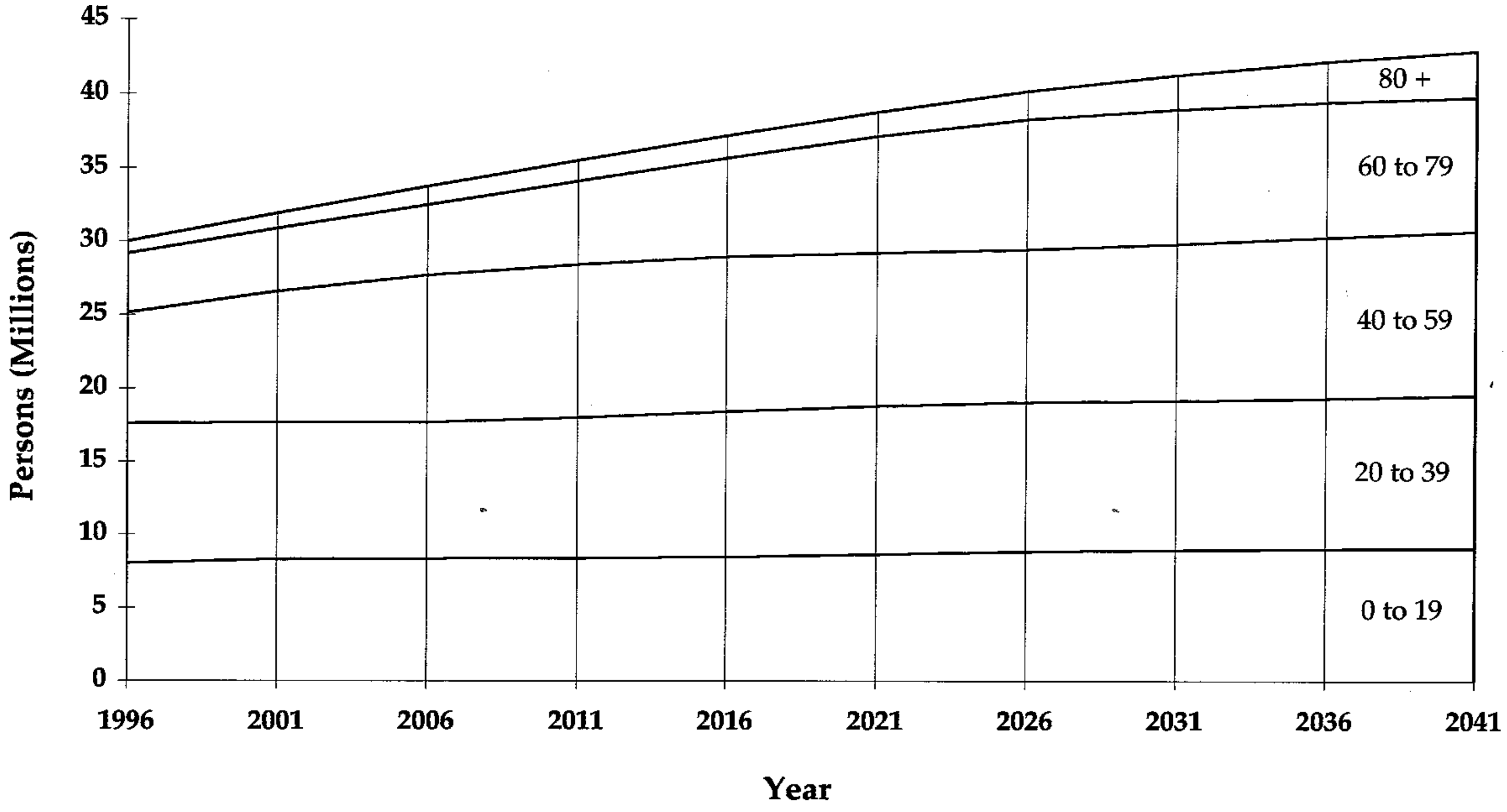

Figure 4.1. Canadian Population Projections. Data extracted from George et al., 1994; Statistics Canada, April 1997.

Increases in population segments over age 60 are especially dramatic. For citizens aged 60 to 79, the rise would be 125 percent, and for persons above 80, approximately 280 percent. Low, medium, and high population growth scenarios were computed by Statistics Canada (George et al., 1994). The three growth scenarios reflect modifications to the assumptions about changes in immigration patterns and birth and death rates. Figure 4.1 and Table 4.1 reflect the medium growth projections.

Table 4.1. Canadian Population Projections from 1996 to 2041.

Year	All Ages (Millions)	60-79 (Millions)	60-79 % of total	80+ (Millions)	80+ % of total
1996	29.96	4.03	13.44	0.83	2.77
2041	42.85	9.05	21.13	3.14	7.33
Percent Change	(+ 43.02)	(+ 124.86)	(+ 7.69)	(+ 278.93)	(+ 4.56)

Changes in the demographic composition of Canadian society will affect the number of drivers in each age category who will be driving in the next century. Clearly, Figure 4.1 and Table 4.1 show that the elderly population will increase dramatically. From these projections, it is clear that societal costs associated with these increases in age categories will require anticipatory research and policy development.

4.2 Canadian Traffic Accident Epidemiology

> *Per unit of exposure, the crash rate of older drivers is higher than average,*
> *and once injured they are less likely to survive*
> (J. Waller, 1985, p. 37).

On a per kilometre driven-exposure basis, U.S. older drivers are over-represented in fatalities and injury severity in most problematic accident configurations, such as left turns and merging (Evans, 1988a, 1988b, 1991a, 1993). Canadian accident rates are often assumed to be like those in the U.S. However, it is difficult to believe that Canadians are exactly like Americans in driving style (e.g., aggressive versus passive-aggressive), weather experiences (e.g., prolonged winter weather), and roadway type (e.g., interstate versus primarily secondary highways).

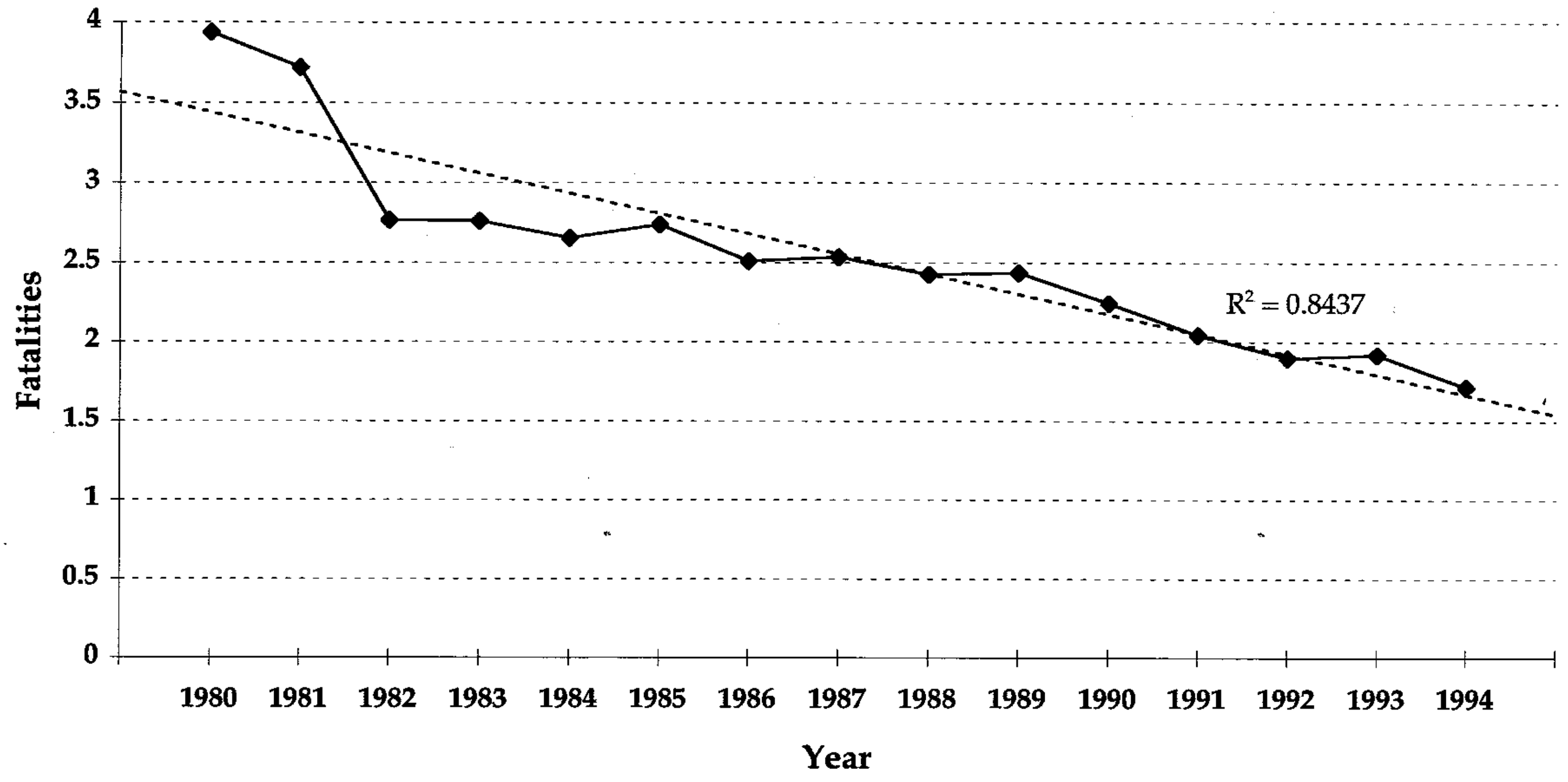

Figure 4.2. Canadian Traffic Fatalities per 10,000 Licensed Drivers. Originally from Canadian Motor Vehicle Traffic Collision Statistics, TC 3322, Transport Canada.

Using available Canadian vehicle registration data, Figure 4.2 was created. It shows a consistent decline in traffic fatalities and injuries per 10,000 licensed drivers from 1980 to 1994. The decreasing linear regression line for traffic fatalities (Figure 4.2) reveals a strong positive correlation ($r^2 = 0.84$) with fatality data. The decline in fatalities, as indicated by the linear trend, has been consistent across the 14 years for which fatality data are available.

The decline in fatalities per 10,000 licensed drivers is a consistent finding (see, e.g., Evans, 1991b). Many U.S. researchers have reported a steady decline in accident rates during the last two decades. Massie et al. (1995) found a decrease in fatalities and injuries for all age groups for U.S. drivers from 1983 to 1990. Cerrelli (1994) also showed a consistent, yet modest, decline in fatal involvements from 1975 to 1990, even with an increase in licensed drivers for the same years. Reductions in fatalities have been attributed to advances in emergency medicine, engineering changes to roadways, vehicles and traffic control systems, changes in individual driver behaviour, and legislative restrictions (Evans, 1991b).

Fatalities across a slightly smaller time period from 1984 to 1995 by age group were examined. The age groups 16 to 24 and 25 to 34 show pronounced declines (see Figure 4.3). A drop in the number of fatalities in the youngest age group from approximately 1,750 to 1,050 or 700 fatalities per year is evident which is a decrease of 42% over 12 years. Similarly within the 25 to 34 age category, fatalities decreased from approximately 1,500 to 1,100 or 400 fatalities per year which is a 25% decrease in the span of 12 years. For older drivers over the same time period, fatalities per year are relatively constant and increase very slightly. Thus, the overall decline in Canadian fatality rates is most likely attributable to fatality reductions in younger driver age groups.

Traffic injuries (see Figure 4.4) also show a decreasing trend, and a strong correlation, $r^2 = 0.92$ using a 4th order polynomial equation. While a decreasing trend is evident, traffic injuries have been declining in a cyclical fashion with dips and rises during the 14 year time window.

In 1995, there were 4,497 persons involved in fatal driving accidents in Canada. Figure 4.5 depicts the number of fatalities by age group based on data obtained from Transport Canada for 1995 (Boufford, 1998). Fatalities were not segregated into the categories of motor vehicle driver, passenger, and pedestrian. Thus, frequencies represent an aggregation of these fatalities types. Direct comparisons to data that separate pedestrian fatalities from motor vehicle fatalities should be made with caution. Similarly, distance traveled (i.e., exposure) and age cohort size were not controlled for in the data. As a result, interpretation is at best tenuous.

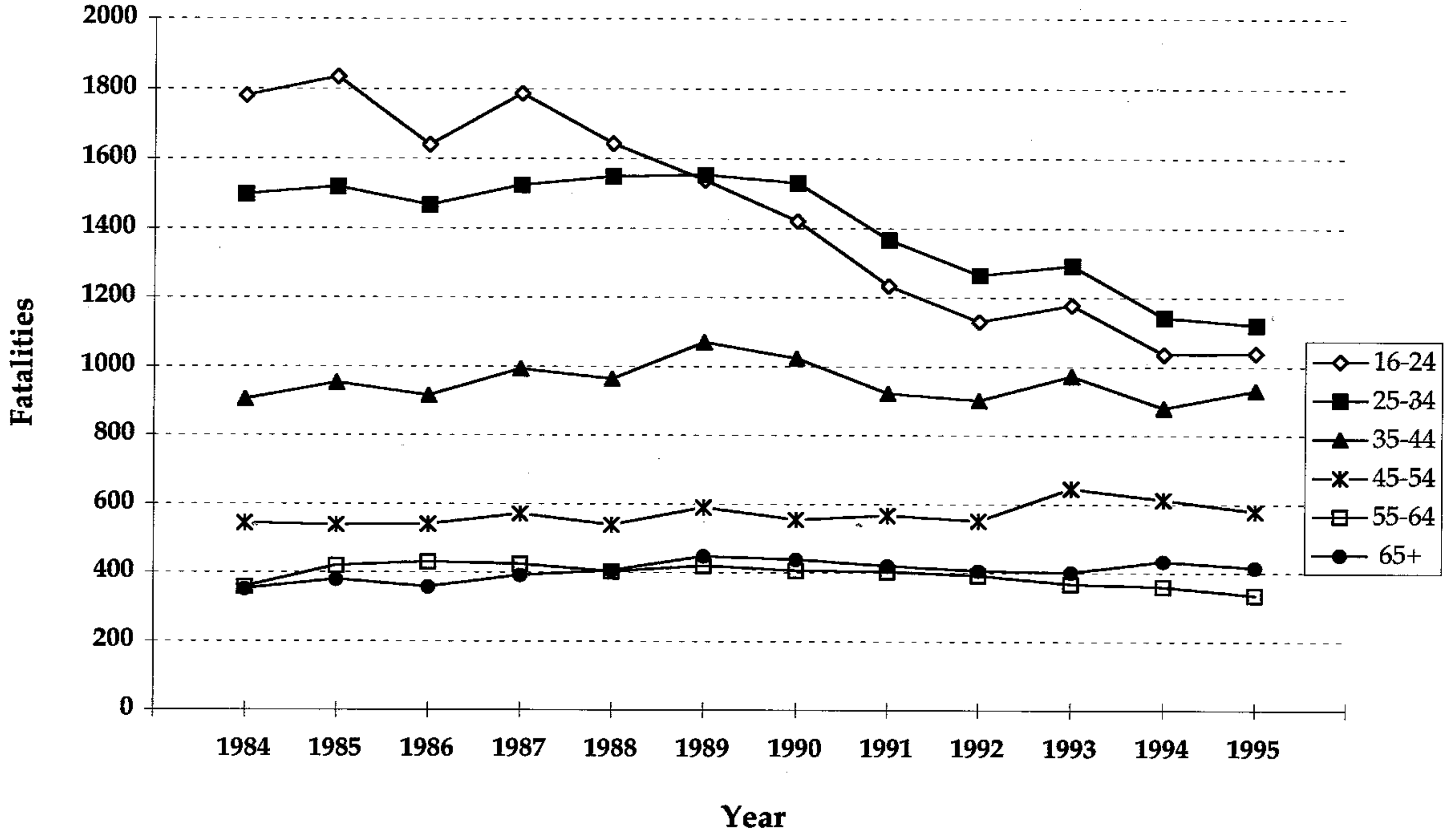

Figure 4.3. Canadian Traffic Fatalities from 1984 to 1995. Original data from TRIAD Databases, Transport Canada, Road Safety.

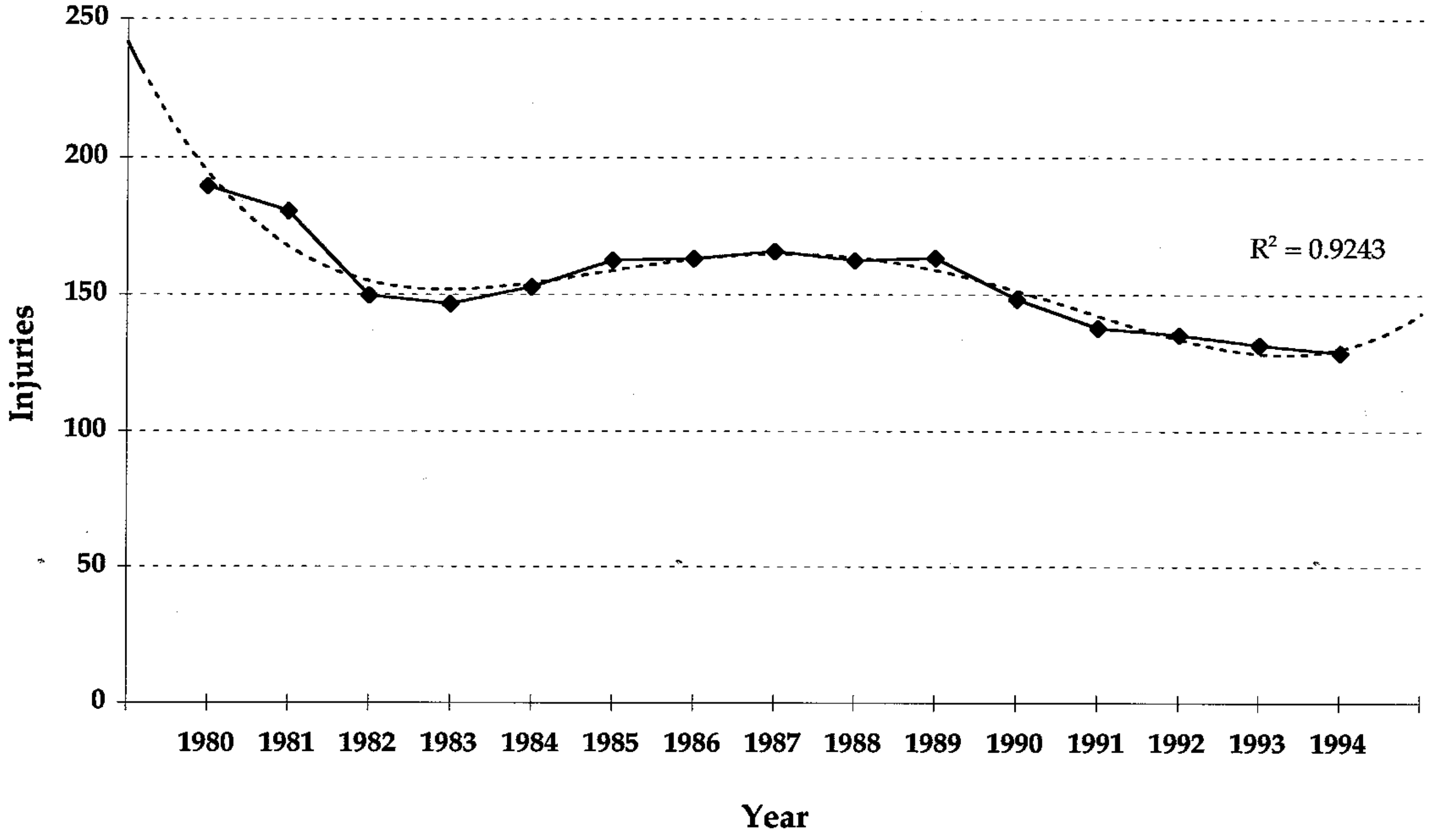

Figure 4.4. Canadian Traffic Injuries per 10,000 Licensed Drivers. Originally from Canadian Motor Vehicle Traffic Collision Statistics, TC 3322, Transport Canada.

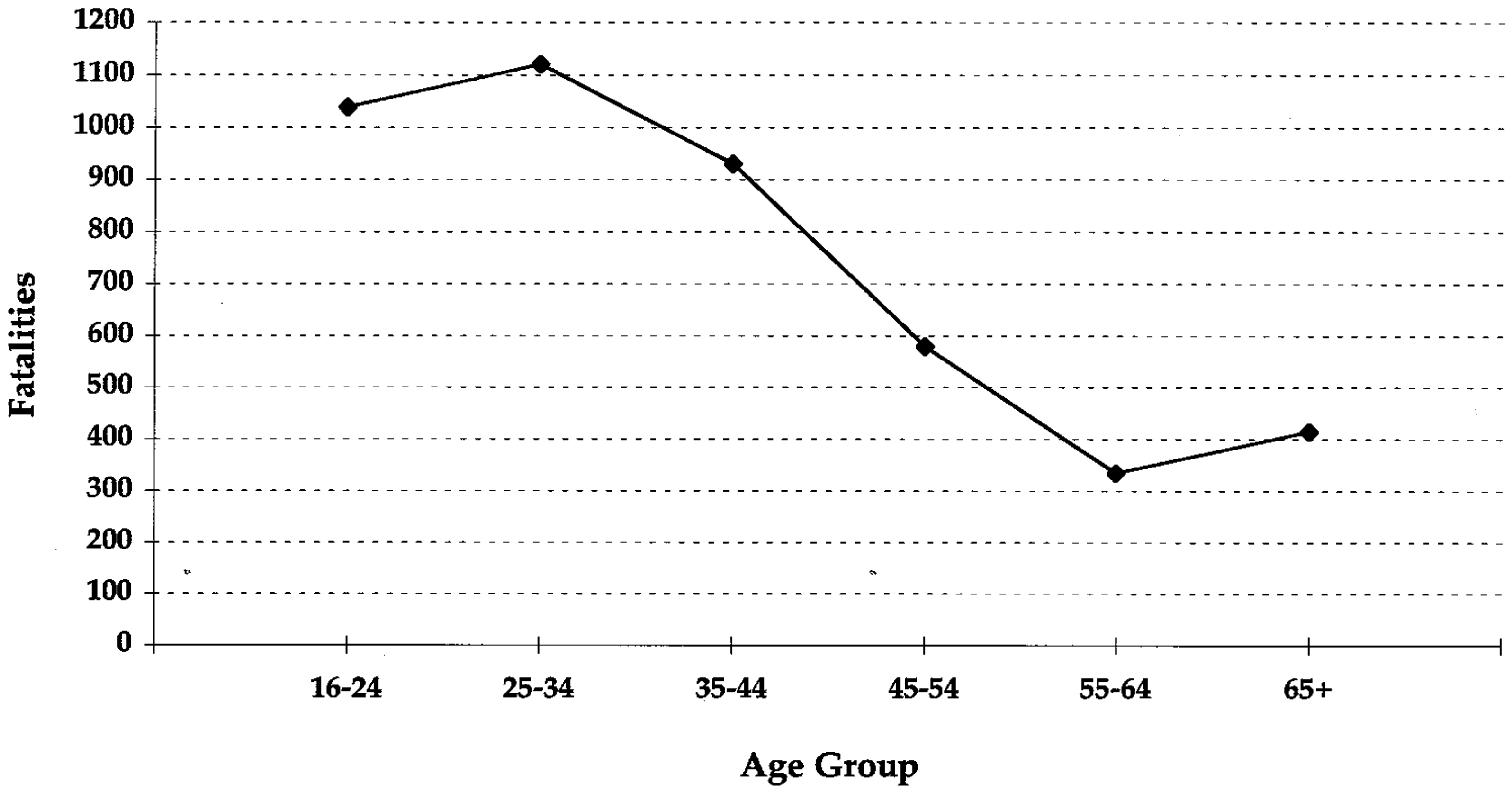

Figure 4.5. Canadian Traffic Fatalities (1995) by Age Group. Original data from TRIAD Databases, Transport Canada, Road Safety for 1995.

An increase in total fatalities for older drivers (65+) is evident. Among all age groups, the highest number of fatalities was in the 25-34 age group. Male fatalities are consistently higher than female fatalities (see Figure 4.6). Even though the total number of accidents for older drivers is lower in comparison to other age groups, the rate at which fatal accidents occur for older drivers rises when exposure to the driving environment is taken into account (Cerrelli, 1989; Evans, 1988a; Graca, 1986; Hakamies-Blomqvist, Johansson, and Lundberg, 1995; Libertiny, 1997; McKelvey et al., 1988). In these previous studies driver age is plotted against driver fatalities. It reveals a U-shaped curve when kilometres or miles traveled is held constant for each age group. The ends of the 'U' indicate higher fatality rates for younger (18-24) and older (65+) drivers. Because the data depicted in Figures 4.5 and 4.6 have not been adjusted for exposure and age cohort size, the slight upturn of the fatality frequency for the 65+ age group should be interpreted cautiously. Interpretation of other data sets allows society conducts triage on where to concentrate intervention resources to reduce these societal costs, the ends of the U, which represent older and younger drivers, are obvious starting points. The unavailability of corrected fatality data is somewhat surprising given the social cost of traffic fatalities in Canada.

In summary, there has been a decline in both fatal and injury accidents in Canada since 1984. This overall decline has primarily been for drivers aged 16 to 34. Overall, accident rates for drivers above the age of 65 have risen slightly however, over the 1984 to 1995 period. For 1995, a greater number of males were involved in fatal accidents than females, for all age categories. This data pattern has persisted since 1984. Within the male group for 1995, there is a slight rise in accidents as drivers age beyond 65 years (see Figure 4.6), which may or may not be indicative of an increase in accidents for older drivers.

4.2.1 Gender

Demographic trends indicate that the number of licensed older drivers, especially women over age 65 will grow dramatically in the next three decades (Cerelli, 1994; Eberhard, 1996). Women, at present, exceed men by a ratio of 4:3 at 65 and up to 2:1 for those over age 80 (OECD, 1990). Figure 4.7 shows a slight increase in fatalities for both male and female drivers above the age of 65 between 1984 and 1995. Overall, there was a 15 percent increase in male fatalities and a 30 percent increase in female fatalities between 1984 and 1995. Comparative statistics for drivers 16 to 24 show a reduction of fatalities of 42 percent, and of 25 percent for drivers 25 to 34 (see Figure 4.3).

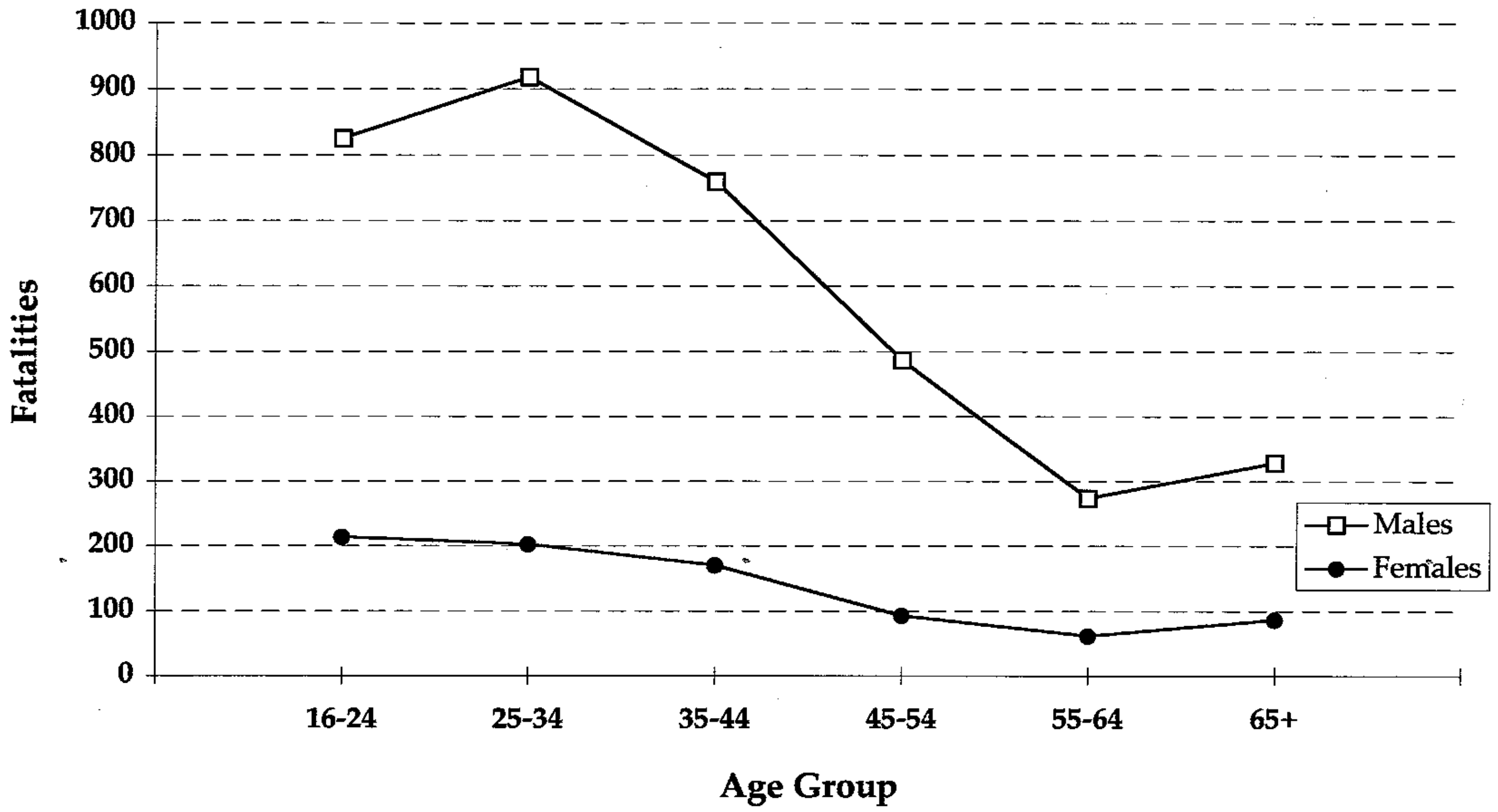

Figure 4.6. Canadian Male and Female Traffic Fatalities. Original data from TRIAD Databases, Transport Canada, Road Safety for 1995.

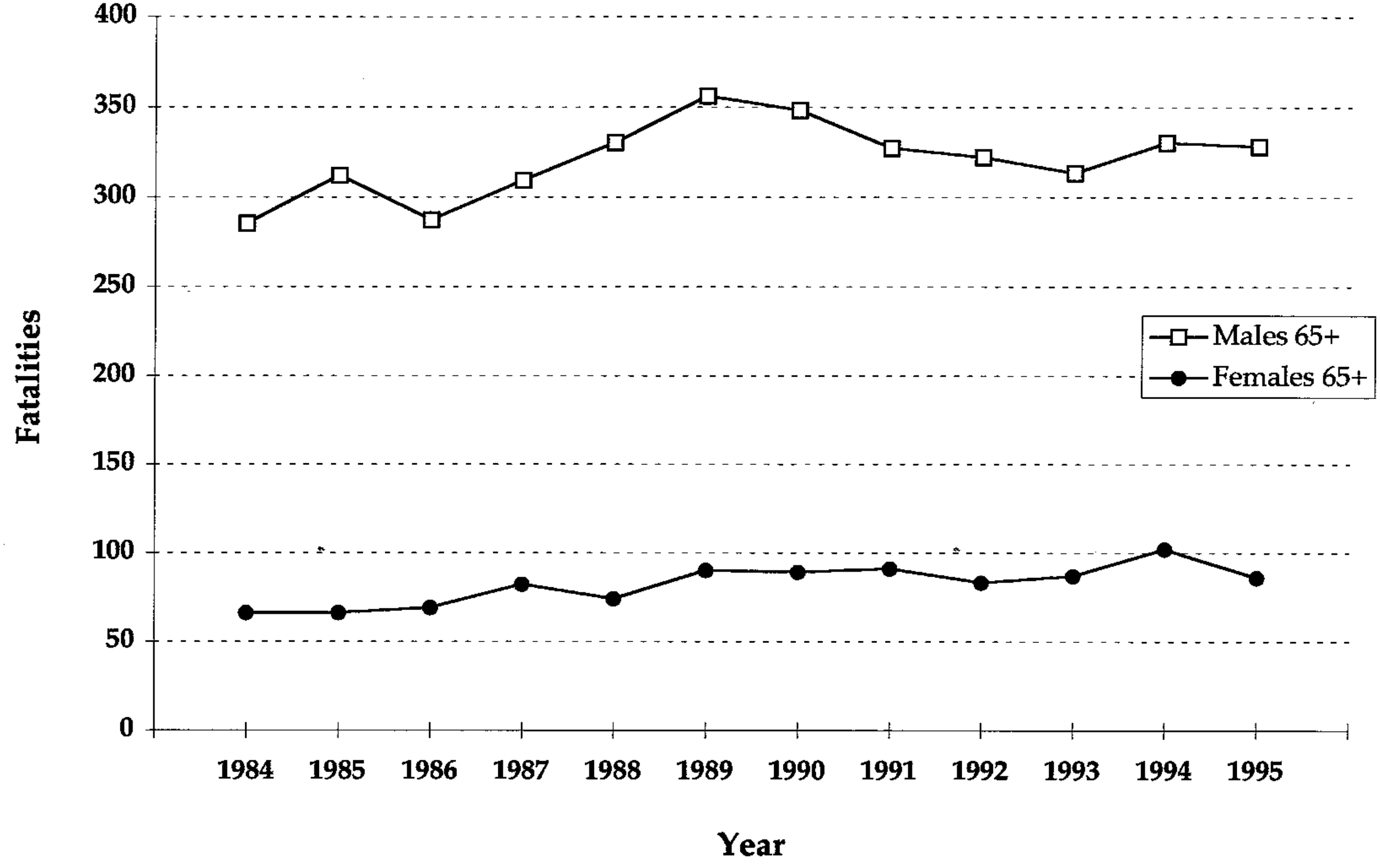

Figure 4.7. Canadian Fatality Rates for Drivers Aged 65+. Original data from TRIAD Databases, Transport Canada, Road Safety.

U.S. data on gender differences among older drivers have revealed trends that differ depending on the years for which the accidents were analyzed. Evans (1988a) found slightly higher older male fatality accident rates for data from 1981 to 1985, while Massie et al. (1995) revealed the opposite trend with higher older female fatal and injury involvements for accident data from 1990. Massie et al. (1995) also found higher accident rates for both male and female older drivers during day light conditions, and higher night time accident rates for younger drivers. When female driving exposure was equated with male driving exposure, Massie et al. (1995) showed, using a regression analysis, that the crash rate of female drivers would be similar to male accident rates. Although Canadian fatality frequencies are not equated for exposure, the difference between male and female fatalities narrows after age 55, which is in agreement with Massie et al.'s (1995) findings.

4.2.2 Driver Exposure

Most American-based researchers have used the Fatal Accident Reporting System (FARS) for accident data and the Nationwide Personal Transportation Study (NPTS) for travel exposure data. Researchers note that the most reliable way of developing travel exposure data is via vehicle-miles traveled (VMT) or vehicles-kilometres traveled (VKT). This allows easy comparison for fatality and injury data for different age and gender groups (see, e.g., Massie et al., 1995). Other researchers (e.g., Hakamies-Blomqvist et al., 1995) have employed the number of license holders as an index for traffic environment exposure. License data use is endorsed when distance traveled information is not available.

Drivers in the future will live longer, but will not necessarily drive as much as they do now. There is evidence that as age increases, motorists drive less often and for shorter distances (Cerrelli, 1994; Massie et al., 1995). Older drivers choose to drive less, yet are involved in more accidents per kilometre driven. If older drivers in Canada do drive less as they age, then the slight upturn in accident rate with older age shown in Figures 4.5 and 4.6 may be more accentuated when exposure is taken into account. If driver exposure (VKT) is controlled and older drivers drive less than younger drivers, then accident frequency per million kilometres of travel would show a sharper increases for the 65+ age group. With a projected increase in elderly citizens in Canada (see, Figure 4.1 and Table 4.1), and if the number of persons who drive rises, then the rise in accident rates for this age category is expected to continue (see Williams and Carsten, 1989, for U.S. projections).

Care must be taken if license data from different licensing agencies are used for the purpose of estimating relative exposure. Different agencies may not have the same level of strictness in their granting of licenses. Thus, in some regions within a country those drivers that are less capable might be allowed to drive, whereas in another region, problematic drivers may not be allowed to drive. Older driver licensing renewal procedures across Canada are somewhat variable. Therefore, the use of licenses as an indicator of driving capability or exposure is likely to be problematic. In addition, a lower licensure rate was found for older drivers in Ontario (Ontario Ministry of Transportation, 1994). Reasons for not being licensed are that they never held a license (e.g., Sivak et al., 1995), lost their capability to drive, or chose to stop driving for economic- or age-related reasons (TRB, 1988). A greater percentage of drivers in younger age groups hold drivers licenses. Thus, as these age groups reach maturity, the proportion holding a license is expected to increase.

While some license data are available from Transport Canada (see Figures 4.2 and 4.4), licensure categorized by age and gender has been difficult to obtain. Because Canadian licensure is not federally regulated, and is in the jurisdiction of the provinces, differing licensing criteria are used throughout Canada. To avoid relying on driver registrations to nominally base exposure, it is essential that a Canada-wide survey for VKT data be performed, similar to the NPTS done in the U.S. Canadian VKT data could be used to more precisely describe fatalities and injuries based on the fundamental measure of exposure.

4.2.3 Age Categories

The single age category of 65+ masks which age groups have greater or lesser fatalities and injuries. Transport Canada, in anticipation of increases in older drivers, also needs to re-categorize 65+ into 65 to 74, 75 to 84, and 85+. If this re-categorization is performed, the age categories of 75 to 84 and 85+ are likely to reveal fatality and severe injury increases similar to U.S. statistics, such as those compiled by Evans (1988a). He does note difficulties experienced in obtaining relevant statistics for drivers beyond the age of 65, and suggests avoiding classifying elderly drivers into broad aggregate categories. Typically, fatalities and injuries accelerate in the later categories of 75 to 84, and 85+ (Evans, 1988a; McKelvey et al., 1988). Accident data may also reveal a critical difference between Canadian driver collision rates, both fatal and injury, and U.S. rates. For example, approximately 1 million Canadians go to the U.S. during the winter months, which would have the net effect of reducing accidents in Canada and subsequently increasing accidents in states such as Florida, Arizona, and California.

4.2.4 Summary and Recommendations

The Canadian population is expected to increase in the next forty-five years with dramatic increases in the age categories of 60 to 79 and 80+. The proportion of these age categories that retain their drivers licenses is also expected to increase.

Fatalities and injuries, as in many other industrialized nations, are steadily decreasing with time due to a myriad of system countermeasures. For reasons that will be explored in the next two sections (i.e., 4.3 Older Driver Accident Typologies and 4.4. Age-related Loss of Abilities) drivers above age 65 have more fatalities than other age categories except those 16 to 24 and 25 to 34. Males have higher fatality rates than women for all age categories. However, if male and female drivers were equated by exposure, this difference may disappear (see, e.g., Cerrelli, 1994). If older driver accidents were adjusted for exposure, an increase in accidents per kilometres traveled is expected.

A number of weaknesses were found in available Canadian fatality and injury data. Being able to determine which demographic groups have the highest accident rates is not possible given the analytical status of Canadian fatality data. If known, resources could be directed to combat the social losses incurred by traffic fatalities and injuries. The intent of the following recommendations is to rectify this situation:

- There is a need for a Canada-wide survey for travel exposure data (see, e.g., Ontario Ministry of Transportation, 1991; Stewart, 1997). Travel miles or kilometres are considered the most valid measure for exposure to the driving environment. A more detailed understanding of Canada-wide travel patterns stratified by age and gender is needed so that an accurate picture of older driver fatalities can be described. Once created, this information should be made available to researchers and analysts on CD-ROM.
- Drivers above the age of 65 years who are involved in accidents should no longer be lumped into a 65+ category. Separation of older drivers into categories of 65-74, 75-84 and 85+ is recommended.
- The categorization of accident data into a standard comparable format is needed. For example, some accident information was categorized as fatal accidents per motor vehicle driver, passenger, and pedestrian, while other data were summed into one general, traffic user category.
- License rates should be categorized by driver age and gender. License rates for age and gender would provide nominal exposure information.

4.3 Older Driver Accident Typologies

The increased fatality rate for older drivers is, in part, due to the differential impact that traffic accidents have on older and younger drivers. As drivers age they drive less, increase their use of seat belts, and drive bigger cars (Graca, 1986). Older drivers are involved in different kinds of accidents than younger drivers (Knoblauch et al., 1995; McCoy, 1991; McKelvey et al., 1988). For example, older drivers are more likely to be involved in an accident at an intersection (McCoy, 1991), while merging (McCoy, 1991), and run off the road (Knoblauch et al., 1995). In contrast, older drivers are less likely, when compared to younger drivers, to be involved in accidents where they were following too closely, driving too fast for conditions (Knobluach, et al., 1995), or after consuming alcohol (Graca, 1986). Traffic and environmental contexts where older drivers appear to have more accidents than younger drivers are described below in greater depth. All accident typologies are based on U.S. data. Low illumination, nighttime, and fog accidents are included because these are hypothetically the driving conditions that would benefit from VES.

4.3.1 Multi-vehicle and Single Vehicle Accidents

Older drivers have a higher accident involvement rate in multi-vehicle accidents in urban settings, when exposure to the driving environment is taken into account, than do younger drivers (McCoy, 1991). Involvement in rural accidents, for older drivers, is somewhat higher than urban accidents (Knoblauch et al., 1995). The types of accidents where older drivers are found at fault are usually right-angled and rear-end crashes, rather than head-on collisions (Mortimer and Fell, 1989). They are also more likely to be found culpable in backing and parking accidents (McCoy, 1991). Most often the older driver is, however, cited for being at fault in accidents where the vehicle is struck.

Intersection accidents are more probable as age increases. Intersections are complex and have the potential to divide attention, so decisions must be made quickly. These factors in combination may increase the likelihood of accidents. Stamatiadis, Taylor, and McKelvey (1990), by analyzing intersection accident data from Michigan (1983 to 1985), found that as age increases beyond 60 years, there is a increased tendency to be at fault for an accident at an intersection. Specifically, drivers 70 to 74 years of age had a 32 percent higher probability of being at fault for causing an accident than not. This probability rose even higher for drivers above 75 to 89 percent. The likelihood of an accident is therefore highest for drivers above the age of 75 (McCoy, 1991).

The rise in these accidents is, in part, due to an increase in the types of violations that older drivers commit. As age increases so does the probability that an accident's occurrence is due to a violation (Graca, 1986; Stamatiadis et al., 1990). For younger drivers, driving violations that most often result in accidents are alcohol consumption (Charness and Bosman, 1992), excessive speed, and following a vehicle too close. Failure to yield right of way to other motorists is cited to a lesser degree. As drivers age violations for alcohol, speed, and following too close decrease, whereas failure to yield right of way, and improper lane use/passing violations increase (Cerrelli, 1989; Knoblauch et al., 1995; Stamatiadis et al., 1990). Right-of-way infractions by older drivers are especially prevalent at high-volume intersections (McCoy, 1991) with multi-phase signals, which may add decision complexity for older drivers (Charness and Bosman, 1992; Stamatiadis et al., 1990). Visual clutter from a variety of signs, signals, and advertising compete for visual attention. These seem to be associated with a high number of older driver accidents, especially at right turns (McCoy, 1991).

Higher accidents with increased age are not solely due to failures to yield right of way. As age increases so does improper handling during turning manoeuvres (Stamatiadis et al., 1990). For example, an older driver, while turning left from a minor to a major roadway, may cut it too close and strike a waiting vehicle (Harkey, 1995). Older drivers have perceptual difficulties in judging gaps in oncoming traffic (Hancock and Caird, 1993; Stamatiadis et al., 1990), and in perceiving vehicles coming from the left and right (Mortimer and Fell, 1989). Older drivers occasionally make left and right turns from lanes where these turns are not allowed (Harkey, 1995). In addition, older drivers have difficulty making right turns with small radii. As a result of not being able to hug the curb lane they enter adjacent lanes. Older drivers have stated that they do not know when turning right on a red signal is allowed and have problems knowing which lane to enter once a turn has been made (McCoy, 1991).

Older drivers have more rear-end accidents at non-intersection locations than do younger drivers. Older drivers, when struck from behind, are cited for either going too slow (i.e., relative to traffic flow) or braking unexpectedly (Mortimer and Fell, 1989). Following drivers tend to expect them to maintain the speed at traffic flow and not brake suddenly. Accidents of these types are more common in high-volume urban settings (FHWA, 1990).

For single vehicle accidents, older drivers are more likely than younger drivers to be cited for failing to yield to other drivers while making a lane change (Knoblauch et al., 1995). Older driver lane change accidents typically occur while merging on or off highways, or when trying to pass other drivers. Older drivers have more single vehicle run-off-road accidents at nighttime (Stamatiadis et al., 1990), especially older males (Mortimer and Fell, 1989). These accidents often take place in rural settings when the older driver is fatigued or falls asleep (Knoblauch et al., 1995; Mortimer and Fell, 1989).

4.3.2 Low Illumination Accidents

Older drivers are involved in relatively more accidents during low illumination conditions than are other age groups. Owens and colleagues (Owens and Brooks, 1995; Owens and Sivak, 1996) queried the FARS accident database for the years 1980 through 1993, for the twilight period (4 to 7 a.m. and 5 to 8 p.m.). During the winter months, the twilight period is immersed in low ambient (natural) illumination and during the summer months it is immersed in high ambient (natural) illumination. Their analysis revealed that more pedestrian fatalities took place during winter twilight periods (i.e., low ambient illumination) than summer twilight periods (i.e., high ambient illumination). Pedestrian fatalities also increased in the presence of inclement weather (e.g., fog, snow, and rain) (Owens and Sivak, 1996). As age increased, for both male and female drivers, so did involvement in pedestrian and cyclist fatalities. The highest male driver involvement for these types of accidents was from at 65 to 74 years, whereas higher female driver involvement was from 55 to 64 years. Pedestrian accident rates appear to decline to rates similar to younger driver levels after retirement (Owens and Brooks, 1995). Fatalities, other than pedestrians and cyclists, did not differ between low and high illumination twilight periods. However, drivers who had consumed alcohol were involved in more accidents resulting in vehicle fatalities than pedestrians fatalities. Owens and Sivak (1996) conclude that during twilight periods, pedestrian/cyclist fatal accidents could be attributable to reduced visibility, whereas alcohol was a larger factor in fatal accidents for other classes of road users.

The highest driver accident rate during daylight conditions, for all fatal accidents, was for drivers above 65 years of age (see Knoblauch et al., 1995). Male and female rates were similar. Younger male drivers were involved in a disproportionately high number of nighttime fatal accidents. Male drivers, of all ages, had higher accident rates during nighttime hours than female drivers, who in turn had higher daylight accident rates (Owens and Brooks, 1995).

Research by Owens and colleagues (Owens and Brooks, 1995; Owens and Sivak, 1996) has shown that older drivers are involved in more fatal pedestrian accidents during low illumination conditions than high illumination periods. Bad weather (e.g., snow, fog, rain) exacerbates the problem. Preventive measures aimed at compensating older driver visual abilities should be advocated. In particular, enhancing the contrast of pedestrians and critical environmental features is an appealing countermeasure (see, e.g., Waller, 1985).

4.3.3 Nighttime Driving

Many older drivers mention that they have difficulties driving at night (Kline et al., 1992). Elderly drivers, based on 1983 NPTS, took nighttime trips for the following reasons: social or recreational (26.5%), visiting friends or relatives (18.4%), family or personal business (16%), and shopping (16%). However, older drivers also report that they often decide not to drive at night (Chu, 1994). For example, the effects of glare from oncoming vehicle headlights have been found with increasing age (Dunne, White, and Griffiths, 1993). Using 1983 FARS data, Mortimer and Fell (1989) found that older drivers (65+) had fewer nighttime accidents (6 p.m.–midnight and midnight–6 a.m.) than younger drivers (< 25), but more than drivers aged 25 to 64. Knoblauch et al. (1995) also found that older drivers are less involved in single vehicle accidents between 11 p.m. and 6 a.m. Data for older females, like most accident-age curves, showed fewer accidents than older males. In most accident involvements the older driver's vehicle is struck by another vehicle, rather than it striking other vehicles, especially during nighttime conditions (Mortimer and Fell, 1989). Only 5% of all nighttime trips are taken by those over 65.

Inherent to safe driving is our ability to see critical objects and manoeuvre effectively through space. These two activities are naturally served by two different visual systems (Leibowitz, 1996). The foveal mode, is located primarily in the central area of the retina, and serves recognition and identification. The ambient mode is principally located in the periphery of the retina, and subserves guidance and orientation. During nighttime low visibility conditions, the foveal mode is detrimentally effected while the ambient mode is not. This selective degradation of vision (Leibowitz and Owens, 1977), results in drivers not being able to notice low contrast objects, especially pedestrians, in the roadway during low illumination conditions. As the ambient mode remains stable, drivers do not experience degradation in ability to manoeuvre along the roadway, and therefore maintain levels of speed similar to daytime conditions. Leibowitz and Owens (1977) argue that because the guidance mode stays stable, and high contrast objects are readily visible at night, drivers do not comprehend the reduction in ability to perceive and identify low-contrast objects. This lack of awareness, in conjunction with the relatively small number of pedestrians who are actually on the roadway, leads to a reluctance to decrease speed and increase vigilance. The selective degradation concept is therefore helpful in explaining why low-illumination accidents, especially those that result in pedestrian fatalities, occur (Leibowitz, 1996).

4.3.4 Driving in the Fog

When driving conditions are degraded by weather, such as when it rains or snows, older drivers are under-represented in accidents. It is likely that they choose not to drive in these conditions. For those who do, a number of issues have been discussed that reveal why the driving perceptual task becomes more difficult (Knoblauch et al., 1995).

A driver uses rate-of-change information in the visual array to detect the vehicle's velocity and by occasionally checking the speedometer (Schiff and Arnone, 1995). Rate-of-change information is specified by the movement of nearby trees, buildings, sign posts, and so forth. Because driving is a task that requires constant vigilance of the external environment, the driver perceives the external environment's rate-of-change information directly and not necessarily from the speedometer. As the rate-of-change increases so does the perceived velocity. When the rate-of-change matches some internally set desired rate, developed through experience, then further acceleration is no longer needed.

During clear weather conditions, the perceived rate-of-change is the actual rate-of-change. When driving in foggy conditions, the environment degrades so that the rate-of-change information is no longer consistently available. Subsequently, the perceived rate-of-change is no longer the actual rate-of-change; it is lower. If the driver is preoccupied with maintaining safe control of the vehicle in the fog and fails to check the speedometer, then the lower perceived rate-of-change will direct the driver to accelerate in attempting to match it to the internally set desired rate (Moray, 1976; 1990). Even when the driver does look at the speedometer and notices that the actual speed matches (or exceeds) desired speed, the reduced perceived rate-of-change will suggest to the driver that the vehicle seems to be traveling at a speed slower than indicated by the speedometer. This will be the case even when the driver adjusts desired speed accordingly in adverse weather.

These theoretical reasons have been supported by simulator-based research findings. A reduction in mean speed for vehicles in both fast and slow lanes has been observed (e.g., Nilsson and Alm, 1996). This reduction in speed is not sufficient to allow necessary sight distance required to brake and stop before a hazard (Harms, 1993; Nilsson and Alm, 1996). Drivers' lateral control of their vehicles within lanes also becomes highly variable in reduced visibility. Vehicles also tend to "bunch up" or platoon together, resulting in reduced headways between vehicles. Hawkins (1988) attributes this platooning to the need for drivers to associate themselves with vehicles ahead and adjacent to them. The tail-lights of leading vehicles act as guides for roadway configuration judgments (Moray, 1976).

Driving in fog has been shown to be difficult for the driver as perceptual information degrades. While the driver can make compensatory adjustments by driving in a platoon, he/she cannot always be relied upon to maintain a safe speed. If the driver is going to be focusing on the external environment through the windshield in an attempt to detect rate-of-change information or hazardous obstacles, it becomes essential and prudent that the augmentation of objects be in such a location (i.e., through the windshield). This is especially true for Canadian drivers, as fog is prevalent in low-lying areas, river valleys, lakes, and coastal regions.

4.4 Age-Related Loss of Abilities

Literature reviews on older drivers typically list all the individual abilities that have shown an age-related decline (see, e.g., McKnight and McKnight, 1993; NHTSA, 1989; Sivak et al., 1995; Temple, 1989; TRB, 1988). For example, older drivers' visual, hearing (Kline and Scialfa, 1997), attentive (Ball and Owlsley, 1991; Kramer et al., 1995; Sekular and Ball, 1986), working memory (Salthouse, Mitchell, Skovronek, and Babcock, 1989), decision making (Walker et al., 1997), tracking (Jagacinski, Liao, and Fayyad, 1995), motor control (Seidler and Stelmach, 1996), and dual-task (Kortelling, 1994; Salthouse et al., 1984) abilities decline differentially (Birren and Fischer, 1995; Rabbitt, 1993) with increasing age. Visual and attentive declines are briefly introduced because these abilities are most likely to be affected by VES (Section 5).

4.4.1 Vision and the Older Driver

A number of excellent reviews of vision and aging have been performed (see, e.g., Kline and Scialfa, 1997; Owsley and Sloane, 1990; and Schieber, 1994). Vision and visual health decline with age. Thirty-five percent of those over 70 years of age have visual impairments, as do 65 percent of persons over 85 (Laplante, 1988). Ocular diseases such as macular degeneration, cataracts, open-angle glaucoma, diabetic retinopathy, and retinitis pigmentosa increase with age and may increase the likelihood of traffic accidents (NHTSA, 1989). For example, a person with coincident blind areas in both eyes is twice as likely to have had an accident when compared to a same aged driver without this visual loss (Eberhard, 1996). Older drivers who have had more severe anatomical degradations, such as cataracts and retinal hemorrhaging, are more likely to have stopped driving altogether (Eberhard, 1996). Drivers with dementia or Alzheimer's disease (AD) are 2.2 times more likely to be in a crash (see, e.g., Parasuraman and Nestor, 1991). It is estimated that nearly 80 percent of patients with dementia continue to drive.

A variety of attentional components, such as visual search, vigilance, useful field of view (UFOV), and dynamic visual acuity, are limited in older drivers (Parasuramen and Nestor, 1991). Constrained useful fields of view have shown a relationship to accidents (Owlsley et al., 1991). However, others have questioned this result (Brown et al., 1993; Schieber, 1994).

Vision, perception, and attention generally decline with increasing age. Tables 4.2 and 4.3, are based on Schieber (1994) and Sivak et al. (1995). These tables list the age-related changes in vision, perception, and attention.

Table 4.2 Age-Related Declines in Visual and Perceptual Performance (Adapted from Sivak et al., 1995, which is based on Schieber, 1994).

Visual and Perceptual Processes	**Typical Result as Age Increases**	**Representative Reference(s)**
Eye Movements (Saccades)	More time and saccades are needed to identify targets in the periphery.	Wacker et al. (1993) Scialfa, Thomas, and Joffe (1994)
Dark Adaptation	Relative rate of adaptation does not change with age, but there is a decrease in maximum sensitivity by 0.1 log units per 10 years of increasing age.	Eisner et al. (1987)
Visual Acuity	Decrease in low luminance, low contrast, and high glare conditions.	Sturr, Kline, and Taub (1990)
Contrast Sensitivity	Ability declines at intermediate spatial frequencies, with increased loss at higher frequencies.	Scialfa et al. (1992) Schieber et al. (1992)
Disability Glare	Increased susceptibility. Tolerance decreases exponentially after age 40.	Pulling et al. (1980) Schieber et al. (1991)
Glare Recovery Time	Becomes slower.	Scheiber (1994)
Peripheral Vision	Decreases from 180° in young persons to 140° by 70 years.	Jaffe et al. (1986) Wood et al. (1992)
Motion Detection/ Perception	Complex phenomenon which seems to remain intact with increasing age. Angular detection of forward to away motion does become more difficult.	Schieber (1994)
Time-to-collision	More errors in estimation.	Schiff, Oldak, and Shah (1992)
Velocity Perception	Less sensitive to relative changes in vehicle velocity.	Scialfa et al. (1991)

Depth and Distance Perception	May become distorted at nighttime luminance levels. Requires validation.	Bourdy et al. (1991)
Colour Vision	Increased errors in discrimination of blue-green colours due to reduced retinal illumination.	Knoblauch et al. (1987)
Perception-Response Time (PRT)	Response times to unexpected events increase with age.	Olson and Sivak (1986) Lerner (1994)

Tables 4.3 Age-related reductions in attention (adapted from Sivak et al., 1995, which is based on Schieber, 1994).

Attention Measure	**Typical Result as Age Increases**	**Representative Reference(s)**
Visual Search	More difficult as number of items to be searched within increases, especially when the target and background are similar.	Scialfa et al. (1987)
Divided Attention	Ability decreases.	Ponds et al. (1988)
Attention Switching	No significant changes have been identified.	Hartley et al. (1987)
Sustained Attention	No significant differences have been found due to inconsistent findings.	Parasuramen and Nestor (1993)
Selective Attention	Ability decreases.	Hoyer et al. (1979)
Useful Field-of-View	Narrows.	Owsley et al. (1991)

How robust or competent is older drivers' performance to declines in specific and constellations of ability? Many traffic researchers recognize that accidents as a dependent variable are not necessarily indicative of driver performance, nor are ability measures predictive of accidents. For example, static and dynamic acuity have a weak relationship to the occurrence of older driver accidents (Henderson and Burg, 1974; Shinar, 1977). Relationships between visual performance and accidents are weak (Sivak et al., 1995). Laboratory tasks, or combinations therein, that assess individual abilities do not necessarily measure how basic abilities are used in concert with other abilities while driving. It is clear that the physical body suffers as one ages, and in turn driving performance is affected. That these detriments do not lead to more apparent significant relationships to accidents suggests that older drivers are performing various compensatory behaviours. Accidents are infrequent, in part, because the task of driving, including compensatory changes, is robust to age-related changes.

4.5 Older Driver Behavioural Compensation

> *Societies react to the total number of fatalities, whereas individual drivers cannot react to them because they have no direct experience of them* (Evans, 1991b, p. 355).

An example of the general progression of difficulties experienced by older drivers is found in the everyday need to back out of parking spaces. Where before it was relatively easy for an older driver to turn their head and look behind their car, over time, mirrors were relied on more and more as head movement became more difficult. The right, left, and rearview mirrors provided a reasonable assistance in backing out. However, with more time, using the mirrors also became difficult to use and bumping or tapping other vehicles strategy emerged as a strategy. To determine whether there was more room to manoeuvre, they would back slowly out of a parking space until they lightly bumped another car. This worked for a while until one day the backing speed was a little too fast and the bump became a crash. The driver retired from driving soon thereafter. The point of this real story is that older drivers change their strategies over time and accidents may finally persuade a driver that they can no longer drive safely.

Older driver compensation is broadly construed to mean behavioural adaptations to in-vehicle components such as ITS displays (e.g., navigation, VES), roadway contexts (e.g., freeways, rural intersections), the environment (e.g., night, inclement weather), and other drivers. Research literature indicates that a number of skills required for driving deteriorate with age (see, e.g., McKnight and McKnight, 1993; NHTSA, 1989; TSB, 1988). Health and financial problems, general declines in ability, and poor vision in older drivers can lead to reductions in driving or abandoning driving altogether. Many older drivers become aware of their own deficiencies and compensate for them in a number of ways. For example, older drivers may make three right turns rather than making a left turn because they have difficulty judging the approach of oncoming traffic (Hancock and Caird, 1993). Perhaps the most obvious adaptations are reductions in speed, more cautious behaviour on the road, and driving less under nighttime, bad weather and heavy traffic conditions (see, e.g., Chu, 1994).

Compensation behaviours can be broadly grouped into behaviours that allow the driver more time (e.g., speed reduction), avoid driving contexts that are complex, busy, or uncertain (e.g., intersections, rush hour, unfamiliar routes), and avoid particular conditions (e.g., nighttime, ice and snow). These broad groupings are consistent with reported accidents (see Section 4.3). Systematic analysis of how, when, and why these compensations are adopted has received sporadic research attention.

Table 4.4 illustrates a wide range of compensatory behaviours that have been identified by researchers. The first column of the table illustrates ways that an older driver may change his or her behaviour, while the second indicates studies that have identified this behaviour. The purpose of listing these behaviours is to characterize the range of sensible adaptations that older drivers may adopt.

Table 4.4 Older Driver Behavioural Adaptations

Older Driver Compensation Behaviour	**Reference(s)**
1) Reduce speed (i.e., adopt slower speeds).	Brouwer et al. (1988) Chu (1994) Hakamies-Blomqvist (1994) OECD (1985) Planek and Fowler (1971) Rothe (1990) Ysander and Herner (1976)
2) Reduced number of kilometres/miles driven (i.e., reduce exposure)	Benekohal et al. (1994) Chu (1994) Rumar (1986)
3) Reduce highway driving and increase urban road use.	Benekohal et al. (1994)
4) Avoid peak hours (i.e., rush hours).	Benekohal et al. (1994) Brouwer et al. (1988) Chu (1994) Kline et al. (1992) Kosnick et al. (1990) OECD (1988) Planek and Fowler (1971) Retchin et al. (1988) Rothe (1990) Wood et al. (1994) Ysander and Herner (1976)
5) Avoid limited access highways.	Chu (1994)

6) Do not drive at night.	Chu (1994) Wood (1994)
7) Carry fewer passengers.	Chu (1994)
8) Avoid driving in ice and snowy conditions.	Benekohal et al. (1994)
9) Drive familiar routes.	Wood (1994)
10) Avoid driving in unfamiliar cities.	Holland and Rabbitt (1992)
11) Avoid complex intersections.	Holland and Rabbitt (1992)
12) Increased awareness and scrutiny of surroundings (e.g., blind corners, uneven pavement, obstacles).	Holland and Rabbitt (1992) Rumar (1986)
13) Reduce attentional load (e.g., knowing the driving route, turning off the radio).	McIntosh (1996)
14) Avoid making quick manoeuvres (e.g., go around the block to make another pass at a missed exit instead of making a fast turn).	McIntosh (1996)

Brouwer, Rothengatter, and van Wolffelaar (1988) examined older drivers' ability to engage in appropriate compensatory behaviour. Older drivers, as compared with their younger counterparts, were found in a laboratory simulator test to be poorer at adapting to the effects of a side wind (an index of performance at the operational level), and less efficient at establishing an optimal speed-accuracy trade-off (also an operational level index), however, there were no differences in a measure of "supervisory function on the tactical level". As a follow-up to the laboratory study they matched older drivers' driving ability (as measured by driver examiners) and their scores on tests intended to gauge information processing speed and tactile supervisory control. At the extreme ranges, elementary processing speed and supervisory function on the tactical level were found to be predictive of driving performance. Older drivers appear to use the strategic level to compensate for loss at manoeuvring and control levels.

Older drivers may not be aware of their failing skills. For example, visual efficiency may very gradually decline and go unnoticed (Holland and Rabbitt, 1992). In cases where elderly drivers have had their licenses withdrawn (usually at the instigation of their doctor or of family members), this may come as a surprise to them. While some older drivers make some adjustments in their driving patterns and habits, many lack awareness of just how badly they drive and how much of a hazard they are on the road.

Not all older drivers are aware of changes to their visual capability. Holland and Rabbitt (1992) found no relationship between actual visual acuity (Snellen) and self-rated vision in a study with 80 older participants (aged 50-79). A significant relationship was found, however, between difficulty seeing at dusk and in darkness and avoiding driving at night (r = 0.43). Similarly, a relationship was found between difficulties with bright light and glare and avoiding night driving where oncoming headlights are common. Those who reported making adaptations due to changes in eyesight were more likely to have been in an accident in the last three years. It is possible that their accident was their indication of worsening eyesight.

Participants, who answered a follow-up questionnaire one month after the initial session, said that they had changed a variety of behaviours in a range of daily activities because they were made aware of the visual and hearing deficiencies in the first testing. Non-awareness of visual decline does not lead to sensible adjustments to driving behaviour. However, if made aware, adjustments are more likely to be made in appropriate compensatory behaviours. For example, if older drivers believe that they have difficulties at night, at dusk, in bright sunlight, or from glare, they are more likely to avoid situations where they experience these difficulties. How to provide feedback to older drivers about vision loss is a fundamental objective of a number of educational programs such as 55 Alive, which is sponsored by AARP.

The research on behavioural compensation by drivers in response to improvements in highways or vehicles has been plagued with controversy (see, e.g., Evans, 1985; Michon, 1985; Moray, 1990; Summala, 1988; Wilde, 1994). Some safety countermeasures have been found to bring about changes to more risky behaviour on the part of drivers, while others have not. A summary of the literature by the OECD (1990) concludes that behavioural adaptation occurs for certain vehicle improvements (anti-lock braking systems, studded tires), but not necessarily for others (daytime running lights, seat belts). This OECD review of the literature, however, says nothing about age differences related to behavioural compensation in regard to vehicle modifications.

A number of research directions on behavioural compensation are important. Two conclusions discussed by McIntosh (1996) highlight important research directions. First, it is often assumed that younger drivers do not adopt similar compensatory strategies. Comparisons to younger groups are needed to determine the relative uniqueness of older driver behaviour changes. Second, why a behaviour pattern is changed may not be related to older drivers' loss of ability. Quite the contrary, they have numerous reasons and complex intentions for *why* they adopt particular driving strategies such as not driving during rush hour because it is their civic duty not to. Information about older driver compensation to ITS applications over time is a complete unknown.

4.6 The Older Driver and ITS Technology

> *What works for older drivers will work for the rest of the driving public, and, conversely, an ITS system that fails to serve the older driver will leave a large and increasing segment of the driving public at risk* (Hancock, Parasuramen, and Byrne, 1995, p. 359).

While new technologies are finding their way into our society more and more in recent years (e.g., computers, banking machines), it may be assumed that older people will adjust quickly to their use. However, there is evidence that new devices are not readily understood or easily used by older adults.

A number of assumptions underlie the research and development of ITS products for older drivers. Older drivers are most likely to benefit from and suffer the effects of ITS technologies (Perel, 1998; Stamatiadis, 1994). Older drivers are faced with driving environments (vehicles and roadways) that are undergoing rapid technological changes. While advances such as power steering and ABS may help the older driver (although this is open to debate; see, e.g., Evans, 1996), the older driver may be overloaded by in-vehicle information systems and increases in the complexity of the urban driving environment. Many are unfamiliar and uncomfortable with rapid change, especially in technology. They were not brought up in the computer age and may be distressed when required to operate machines and interpret displays of the high-tech variety. A number of studies are reviewed to highlight issues that older drivers encounter when using ITS systems.

A good example of technology use by the elderly is the automatic teller machine (ATM). Rogers et al. (1996) examined ATM users in four age groups (<35, 35-54, 55-64, and 65+) and found that subjects 55 and older preferred to deal with people and were less likely to use an ATM, as compared with younger subjects. In addition, older subjects felt less comfortable than young ones using the machines. The most frequent difficulty encountered by older users was seeing the screen. In another study, older adults (aged 61-81) were given one of four instructional programs for teaching ATM use. The assessment included performance on four ATM tasks across several blocks of trials. Successful performance ranged from 48–89% for the first six blocks of trials. Average performance after a 24-hour period, for the four teaching methods, varied from about 25 to 57%, suggesting a good deal of difficulty in remembering the correct procedures for ATM use. The most successful training method was found to be the use of hands-on experience and specific practice with critical task components. Initial fear of technology and the need for specific training are recurrent themes of older driver use of many ITS technologies.

4.6.1 Subjective Evaluation of ITS Applications

Sixsmith (1990) examined the expectations of older drivers as they relate to road transport informatics (RTIs). These represented route guidance, anti-collision devices, radio data systems, awareness monitors, and breakdown detection devices. A series of six focus groups of older drivers (age 52-79) discussed driving performance and RTIs. Among the major driving difficulties experienced by drivers were navigational problems, night driving, and declining competencies (e.g., reaction time, perception).

The results indicated that women were more reluctant than men to accept new technologies. Some participants felt that new technology would increase safety and some thought that it was the answer to all their problems. Others were wary of new technology, especially at the driver-machine interface. The five technologies discussed provoked mixed reaction (with no apparent gender differences). When asked whether new technologies would give them increased confidence in situations where they had been reluctant to drive (e.g., driving in central London, or at night), the responses were generally negative. These older drivers did not view the new devices as the solution to their problems. They tended to feel that the RTIs would be of more benefit to younger drivers and business people. Negative opinions were expressed regarding any systems that would startle them (e.g., warnings) or demand more of their attention. "People felt that driving is dangerous enough today without extra problems imposed by RTIs that may be poorly designed, or at least poorly adapted for elderly drivers, especially when such devices are not necessary" (Sixsmith, 1990, p. 44). On the basis of this limited study, there may be reason to believe that new technologies are not the solution to many of the difficulties encountered by older drivers on today's roadways. The participants were skeptical of the value of systems that would present additional warning signals and more information with which they must cope.

Radio data systems, which provide up-to-date information on road conditions, weather, and so forth, were met with enthusiasm. Any device capable of making the vehicle more reliable (e.g., breakdown detection, emergency alert) was especially appreciated by female drivers. These older drivers, in general, were reluctant to give up control of the vehicle (e.g., as with anti-collision devices), and many saw them as potentially replacing proper driver attention to roadway hazards. While this study gathered only subjective evaluations of specific new technologies, it serves to make us aware of some of the potential concerns of the older driver.

4.6.2 Car Phones

For devices that require division of attention, an interaction of age and task complexity is predicted, that is, increases in age will produce greater decrements in performance on one or both tasks. However, one new technology that demands driver attention in much the same way as will other proposed ITS applications is the in-car phone. It has been shown that using a phone while driving can increase the chances of an accident by up to 4.8 times (Redelmeier and Tibshirani, 1997). The primary factor in the link between phone use and accidents would appear to be reduction in driver attention to the events on the roadway.

It is important to consider the extent to which drivers might compensate for the increased risk associated with in-car phone use, for example by reducing speed or increasing headway. In a simulator study of the effects of phone use on driver behaviour in a car-following situation, Alm and Nilsson (1995) found an increase in choice reaction times and shorter minimum headways while using a phone. In addition, elderly drivers had a greater increase in reaction time while phoning than did younger ones. Drivers' mental workload, measured with the NASA-TLX, increased with the phoning task. The impact of phone use on reaction time was greater for the older drivers. In addition, drivers did not compensate for the added demands of the phoning task by increasing headway.

The negative impact of existing in-vehicle technology (the in-car phone), and the apparent failure of drivers to compensate for the diversion of attention resulting from its use, raise the very real possibility that drivers, especially older ones, will have difficulty performing the driving task safely when new ITS devices are introduced into vehicles. Driving while using the phone requires the driver to do several tasks at the same time. Attentional demands to variations in traffic, roadway geometry, signs, and signals are likely to covary with the demands of manipulating a phone (if not hands-free), remembering and dialing numbers, and conversation that has effect, intensity, and complexity.

4.6.3 Navigation Systems

Barham et al. (1994) examined the benefits and safety implications of route guidance systems for 35 elderly drivers (65+) by having the elderly drive a predetermined route, once with and once without Travelpilot a route guidance system. Four separate measures were taken while they were engaged in following the prescribed route: 1) estimation of time spent looking at the Travelpilot was made by a researcher sitting in the back seat of the car; 2) an experienced driver assessor observed the participants' driving technique; 3) pre- and post-questionnaires about the navigation device were administered; 4) mental workload was assessed before and after using NASA-TLX.

No differences were found on assessed ratings of performance by the assessors, although only overall scores are presented. Assessor subscores were not reported such as for steering, braking, anticipation, positioning, and so on. There is no reporting of whether the design of the study was between or within. Whether drivers performed with the Travelpilot and then without or whether counterbalancing was performed was also not reported. All participants were members of the Guild of Experienced Motorists, which may have been indicative of performance of ordinary older drivers. Total time looking at Travelpilot was 7.5% of glances. Males made longer looks (M = 0.73 s) than females (M = 0.63 s). Potential relationship between a measure of working memory and glance frequency (but not glance length), that is, more looks might mean that those with worse memory might need to look back at the display to acquire or refresh a piece of information. The Travelpilot was rated as easy to use. No safety-related problems were found—except when faced with "the dual task of driving and following the route guidance system's instructions". Having a route guidance system of some type might change their driving habits by going to new places or getting out more often.

While investigating navigation systems, Cambell et al. (1995) reported that older drivers (55-85) found the features of TravTek (a specific navigation system) more difficult to learn and to use, and less functional than did a group of younger drivers. There was some indication that the initial reticence to use a system such as TravTek diminished as older drivers gained more experience with it. Thus, initial perceptions of ITS products are likely affected by fear of technology. Until they have adequate experience, the elderly, in general, are reluctant to use technology.

In a second study, older drivers (aged 55–76), interacted with navigation information that was either 100 percent or 77 percent accurate. They were not able to use the more accurate information as efficiently as a younger group of drivers (aged 18-54). A third study, where a delay was introduced between the presentation of a message and recall of it, also produced performance decrements by the elderly group. These two studies highlight the working memory limitations of older drivers. Working memory (WM) is related to the number of times that a driver needs to look at or re-acquire information (e.g., a guidance display) (Oxley and Mitchell, 1995). Thus, older drivers with worse WM are likely to need to look at a display more often than drivers with better WM.

ITS used by older drivers should require minimal training. Systematic training and support may help older drivers to accept and effectively use ITS systems. Information presented to older drivers is likely to be used less efficiently and is likely to decay sooner than for younger drivers (Granda et al., 1997).

4.6.4 A Variety of ITS Applications

Within EDDIT (Elderly and Disabled Drivers Information Telematics), which is a project of DRIVE II, six ITS applications (route guidance, traffic information, emergency alert, reversing aid, night vision, and collision warning) were tested to determine whether older driver mobility was improved or safety compromised (Oxley and Mitchell, 1995; Oxley, 1996). For each system approximately 30 elderly drivers, 10 each within the age ranges of 65 to 69, 70 to 79, and 80+, were sampled. Males and females were approximately balanced within each age range and drivers had to have held their license for five years and still be driving. An overview of the applications and how they were tested is shown in Table 4.5.

Table 4.5 Overview of EDDIT Evaluation of Six ITS Applications (Oxley and Mitchell, 1995, p. 9)

ITS Device	**Specific Scenario**	**Evaluation Procedure**			**N**
		Driving Sim.	**Test Track**	**On-road**	
Collision warning	Right turn (U.K.) across oncoming traffic from a major to a minor road	x			N = 30, 27
Reversing aid	Eight back-up manoeuvres, with and without reversing aid			x	N = 43, 39
Route guidance	Routes in urban and suburban regions			x	N = 27, 35, 30, 9, 7
Traffic information	Highways near Lyon (France)			x	N = 20
Emergency alert	Public road around Cranfield (U.K.)			x	N = 22
Night vision	Prescribed test track route (Sweden and U.K.)		x		N = 31 (UVES) N = 15 (IVES)

Navigation systems that required significant attention caused drivers to reduce speed and steer off course. As the complexity of route guidance increased, basic driving task performance declined, and more so for older than younger drivers. Collision warning and reversing aids, for a variety of reasons, may have little impact on improving mobility. The editors concluded that vision enhancement systems and emergency alert with AVL (Automatic Vehicle Location, Mayday) systems are likely to improve older driver mobility and personnel safety, respectively. Vision enhancement systems (both UV and infrared) seemed to improve the visibility at night of pedestrians and roadway guidance features (also see Section 5). Subjective perceptions of VES indicate that older drivers find the system easy to use (UVES–100%) and they may choose to drive at new times (73%–UVES, 60%–IVES). Emergency alert which provides vehicle location information to a central dispatch centre was viewed favorably.

4.7 Summary

The Canadian elderly population is going to increase dramatically in the coming decades. Given the demographic shifts of elderly age cohorts, a number of transportation policy and research issues need to be addressed. For example, Canadian accident data is lacking in several respects; namely, exposure and proper age categorization (i.e., from 65+ to 65-74, 75-84, 85+). Increases in the numbers of elderly women drivers will be a pressing concern. Older driver accident typologies are dependent on U.S. analysis.

Older drivers' performance on a variety of measures is, on average, worse and more variable than younger drivers. Numerous studies have described the decline of visual, attentive, cognitive, and motor declines in the elderly (see, e.g., Staplin et al., 1990). However, the relationship between laboratory-based measures of abilities, such as visual acuity and contrast sensitivity, despite considerable research efforts and traffic accidents, has achieved minimal success. Testing of older drivers using conventional tests such as visual acuity, is largely unpredictive of traffic accidents. Chronological age is not a particularly good predictor of functional capability (OECD, 1990). More importantly, screening of older drivers is not likely to be welcomed.

How and why older drivers behaviourally compensate for reductions in capability is not well understood. Compensation strategies that give older drivers more time to respond and avoid complex traffic situations and nasty environmental conditions, may be adopted. However, many older drivers are not aware of gradual declines in their visual abilities. Provision of effective feedback and evaluation assistance of older driver skills is essential to their safety and the safety of others (Holland and Rabbitt, 1992).

Accident rates at night and under low illumination conditions for older drivers are not indicative of a "problem" with night driving per se. Older drivers choose not to drive at night because of visual difficulties and because they plan their activities so that they do not have to. Rather, fewer older driver nighttime accidents are likely to reflect the choice not to drive at night. It remains to be seen whether or not older drivers will be more or less inclined to take up night driving if VES become widely available. ITS products may produce compensatory effects by drivers which nullify the safety gains obtained. Research is needed to determine the degree to which in-vehicle ITS can offset declines due to aging processes (NHTSA, 1989). Thus, ITS technologies must, at the minimum, keep pre-existing levels of safety constant.

VES and AVL systems appear to be promising ITS applications for older drivers. Age may not be a good indicator as to who might use an ITS application or how they might perform with it. However, fear of using technology and the need for effective training are significant barriers to large-scale acceptance of ITS applications by older drivers. Therefore, ease of use and minimal training are essential user requirements for ITS applications.

4.8 References

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5.0 VISION ENHANCEMENT SYSTEMS (VES)

The purpose of a vision enhancement system (VES) is to enhance the driver's ability to see hazardous objects (e.g., guardrails and other vehicles) and the roadway (e.g., edgelines), especially during low visibility conditions (i.e., thick fog, rain, snow, and nighttime) (Kyle, 1997). VES have pursed two development paths, namely, infrared vision enhancement systems (IVES) and ultraviolet vision enhancement systems (UVES). The similarities and differences between the two systems become apparent as a technical description and human factors driving simulation and field trials are reviewed.

5.1 Technical Description

There are two types of VES: infrared and ultraviolet. One type uses on-board infrared sensors to detect thermal energy differences in front of the vehicle. These thermal energy differences are then turned into heat picture images which are displayed on the windshield. For example, a pedestrian has a thermal signature that is different from the traffic environment background. Thus, the sensor-display system renders the difference as an outline of the pedestrian. The second type of vision enhancement system uses ultraviolet vehicle headlamps to illuminate the roadway with radiation which causes fluorescent objects to emit visible light. This enhances the driver's ability to see important objects.

5.1.1 Infrared Sensors

In vision enhancement systems that use infrared sensors, the sensor is attached to the automobile at a position (unavoidably) different from the driver's visual reference point. Some sensors, with built-in illuminators, illuminate the anterior roadway with radiation of a specific wavelength and then detect the level of radiation that is reflected back to a sensor array. Others detect radiation that is naturally emitted (e.g., thermal energy) from the driving scene (Parkes et al., 1995). Infrared sensors that face anterior from the car are labeled forward looking infrared (FLIR) sensors. Others directed toward the left and rear of the vehicle may serve as blind spot detectors (Patchell and Hackney, 1997). Both types use thermal energy detectors. Forward facing systems act as vision enhancers by displaying a heat image on the windshield, whereas, blind spot detectors use thermal technology to determine the possibility of a lateral collision.

Earlier generation infrared sensors had to undergo a process called cryogenic cooling of focal plane arrays within the sensor before the thermal scene could be displayed. While this cooling process resulted in high performance, it was also very expensive. Newer, uncooled sensors, do not require cryogenic cooling, and are not as expensive to manufacture. There may, however, be a cost reflected in reduced sensor power with uncooled infrared sensors.

Thermal energy is a form of emitted radiation that is not visible to the human eye. The eye is sensitive to electromagnetic energy within a range of 0.38 to 0.7 microns (μ) or 380 to 700 nm. Infrared sensors can detect radiation at longer wavelengths of 0.8 to 2 μ (near infrared), 3 to 5 m (middle infrared) and 8 to 12 μ (far infrared) (Kiefer, 1995). Blind spot detectors currently being developed use sensors that detect far infrared thermal energy (Patchell and Hackney, 1997). The new uncooled sensors detect thermal energies from 8 to 14 μ.

5.1.2 Infrared Sensor Development Status

Boeing Space Systems-Sensor Products has developed an uncooled infrared sensor (code U3000) that presents TV-like image quality (320 x 240 pixels), reliability (with Silicon Integrated Chip processing), ease-of-use and maintenance (Howard et al., 1997). Boeing has invited product partnerships for development of sensor optics, driver displays, and product integration, distribution, and service.

Raytheon TI Systems has developed an infrared driver vision enhancer called NightDriver (Kyle, 1997). The cited benefits include a preview of the road ahead, detection of pedestrians, animals, and obstacles beyond headlight range, and of suspicious persons hiding in foliage surrounding the roadway (Kyle, 1997). The Raytheon TI Systems NightDriver projects the infrared image on a head-up display (HUD) via video images, and it is claimed that drivers can see better, further and react sooner, through dust and smoke. It is not clear whether this image uses contact analog or non-contact analog HUDs. The NightDriver system has been installed on Hummer off-terrain vehicles and tested in night, racing, and rough terrain conditions. Test results were not reported.

Milton (1997) reports that the U.S. Army has also been developing uncooled infrared sensors for their vehicles. These sensors are in their second generation of development. The enhanced image is displayed on a flat panel display with an image size of 320 x 240 pixels, at an optimal distance from the driver (at approx. 20" or 50.8 cm). Displays in tanks are closer, however, (approx. 10" or 25.4 cm) and can cause eye fatigue and dizziness. Head-mounted displays/goggles were found to be unstable, heavy and required frequent re-adjustment. Milton (1997) notes that the cost of these uncooled infrared sensors (code AN/VAS-5) is, at current design, too high (ranging to a maximum of $20,000).

5.1.3 HUD Technology

Once the infrared sensor detects differences in thermal energy (i.e., heat levels) between an anterior object and its background, then the sensed heat differences are transformed into a heat picture that is visible at the human viewing electromagnetic energy range. The transformed image is displayed on the windshield (for forward enhancements), in real time, using HUD technology (i.e., collimators and combiners). A collimator bends the light rays from an image source using refraction (lenses), reflection (mirrors) and diffraction (holograms) so that it is visible on the windshield at a set focal distance (from the driver's eyes). The VES image thus appears at a level optically equivalent to the objects in the external environment. A combiner, located between the driver and the windscreen, is then used to amalgamate the head-up display image with the external environment (Gish and Staplin, 1995).

Vision enhancement imaging that is overlaid on a HUD, so that the image is collimated at the same location as the objects it augments seen through the driver's line of sight, is referred to as contact analog infrared (Keifer, 1995) or conformal imaging (Gish and Staplin, 1995; Wickens and Long, 1995). The contact analog image overlaid on the object thus forms a primary source of information (about the object) for the driver. Because the VES image is to be overlaid on the external environment, it is essential that its placement is at a reliably close focal distance to the object as seen by the driver.

Conformal imaging is different from speedometer HUDs, for example, that are of a secondary (non-contact analog) source to the driver, and which should be collimated at 2.5 to 4 m in front of the driver (Gish and Staplin, 1995). Blind spot thermal detectors also display hazard information through non-contact analogs, by using flashing lights or auditory alarms (Patchell and Hackney, 1997). Gish and Staplin (1995) state that non-contact analog HUDs should be avoided as they may distract attention from the external environment which is the primary source of information. These types of HUDs are also prone to luminance contrast differences between the HUD image and the external environment, which may render the HUD too bright or not bright enough.

Current HUD technology uses monochromatic images and provides the driver with a field of view (FOV) of 15 degrees horizontal by 10 degrees vertical (Bossi et al., 1997). This FOV is placed at the center of the driver's line of sight. Unless this FOV range is expanded, vision enhancement within the fovea and encompassing regions can be supported, while peripheral vision can not. Vision enhancement in peripheral vision is especially needed for older drivers who are susceptible to a restriction of the useful field of view (UFOV) with increased age.

With a monochromatic display, the vision enhancement image is a distribution of black and white. A polarity setting of "white-hot" shows higher temperature objects as whiter than colder temperature objects, whereas, a setting of "black-hot" shows hotter items as blacker than colder objects (Kiefer, 1995). The driver would need to gain practice and familiarity with a polarity setting before using the system. It is not quite clear how these polarity settings will enhance visibility during nighttime conditions. It would seem that during low illuminations only the "white-hot" polarity setting would be effective.

Thermal image presentation of objects, such as pedestrians, is not reliant upon object colour or lighting conditions. Only objects that differ in thermal energy from the background are displayed. Objects that do not differ in temperature from the background are not visible in the thermal image.

5.1.4 Ultra Violet Headlamps

The second type of vision enhancement system directly illuminates the forward facing roadway, through use of ultraviolet (UV) headlights. According to the Ultralux AB product literature (circa 1997), during nighttime conditions the visibility with UV headlights is extended to 150 m for fluorescent road markings and 200 m for posted signs. Approaching drivers do not experience glare from these UV headlamps.

UV light is of shorter wavelength than that is normally visible by the human eye. It is in a range of 0.32 microns (μ) or 320 nm to 0.4 microns (μ) or 400 nm. When UV is reflected by certain materials (usually fluorescent) it emits light at a longer wavelength back which can be seen by drivers. The UV light source is integrated with the standard lighting system in vehicles, enabling the UV source to complement the standard low beam (Fast, 1994). The combined light bulb is called a luminance discharge lamp.

Low-beam (dipped) headlights limit visibility distance, which is how far ahead the driver can see, to approximately 55 m during nighttime conditions (Fast, 1994). The use of high-beam headlights is not always feasible in urban areas or heavy traffic conditions. High-beam headlights are also susceptible to light scatter and reflection in mist and fog conditions. Sliney, Fast, and Ricksand (1995) claim that low-beam UV headlamp use reduces the scatter of light in inclement weather conditions, such as fog and rain, and does not produce glare in the eyes of oncoming drivers.

Some countries have felt that the use of UV headlights may pose a health hazard to the eyes of drivers (Parkes, et al., 1995). Ultralux AB researchers state that a special filter that eliminates harmful types of UV light, particularly UVB (range 0.28 μ to 0.31 μ) and UVC (shorter than 0.28 μ) can be placed in the headlamps (Fast, 1994). The UVA rays are of the near ultraviolet range (i.e., approximately

0.32 μ to 0.4 μ) and are not considered harmful (Sliney et al., 1995). UVA rays are used extensively in entertainment applications, such as discos and fluorescent signs.

The lens absorbs most of the UVA light. Some (approximately 1 percent) does reach the retina and is perceived as a blue-grayish light that becomes increasingly difficult to look at as direct exposure to the retina increases. An aversion response makes the eye lids close and head move away from the source within a few seconds of initial exposure. A similar response is made when looking at the sun. Sliney et al. (1995) report that direct exposure (i.e., looking directly into the light at a distance of 5 to 10 cm) of more than 50 seconds would exceed the irradiance level that is deemed acceptable by the American Conference of Governmental Hygienists (ACGH). Drivers are not expected to stare into the headlamp for 50 seconds, as an aversion response would be made after only a few seconds. Sliney et al. (1995) claim that direct exposure to UV headlamps, with filters that block UVB and UVC, does not pose a threat to the lens or the retina. Even for incidental viewing by a small child who passes in front (less than one metre) of a vehicle equipped with UVA headlamps, exposure to 200 seconds is not harmful.

As the observer moves further away, then safe viewing duration increases; at 5 m it rises to 10 minutes. Sliney et al. (1995) note that the UVA radiation that is emitted by UVA headlamps is less than the amount emitted by the sun, and as less than one percent of it actually reaches the retina, long term, cumulative hazardous effects are not expected. They do, however, recommend that while the vehicle is stopped at an intersection the emission of UVA radiation be limited. Maximization of the retinal image should also be attempted, such that the radiance of the projection is spread out. Care must also be taken so that UVB and UVC radiation does not become emitted if the headlamp gets damaged. Cumulative effects of UVA radiation on aversion responses such as blinking and looking away are unknown or perhaps unreported.

Objects in or near the roadway, such as lane markings and highway signs, can be made more visible with certain fluorescent pigments that reflect UV light. The National Swedish Road Administration has equipped approximately 100 km of roadway with fluorescent pigments to use for a field test. Wide use is expected to reduce the number of single vehicle accidents (e.g., driving off the roadway).

Common clothes are made of fabrics that contain fluorescent materials which increase the fluorescence of pedestrians when viewed with UV headlamps (Sliney, et al., 1995). Fabrics that naturally contain fluorescent elements include denim, cotton, and polyester. Clothes made of these fabrics are visible at 100 m with UV headlamps and approximately 50 m with low beam standard headlamps (Fast and Ricksand, 1998). The fluorescence of wool and black jeans, that naturally contain lesser levels of fluorescent elements, can be increased by washing them in detergents that contain optical whiteners (Fast, 1994).

5.2 Driving Simulator Infrared VES Studies

Nilsson and Alm (1996) performed a simulator study with three conditions: driving in fog with or without a vision enhancement system, and normal driving (without fog) in a Saab Automobile AB. The VTI simulator consisted of six subsystems: a simulation model system, a moving base system, a 120^0 wide visual system, a vibration-generating system, a sound system and a temperature-regulating system. The vision enhancement simulation was created by taking a black and white image (17 x 12 cm) from the normal (without fog) simulated drive, and presenting it on a monitor which was positioned at the center of the windshield area directly in front of the driver's forward line of sight. Thus, the center view of the participant was clear black and white, while the periphery view was foggy.

The 24 participants drove on a two-lane simulated road and responded to an unexpected event by pressing the brake. Mean driver speed was lowest for the fog condition and highest for the normal visibility condition. The use of the simulated VES during fog visibility significantly increased driver speed from the fog condition, but did not reach the speed driven in the normal visibility level. Variability in speed was highest when the VES was used. The simulated vehicle's lateral position in the lane was closest to the center line in the fog visibility condition and furthest in the normal driving scene. Variability in lateral position was again highest for the VES. Brake reaction time and distance traveled after the presentation of the simulated, unexpected event, were equal in the normal and fog with VES conditions. Brake reaction responses during the fog condition were significantly slower.

While the results suggest that the simulated VES enhanced drivers' ability to drive faster and respond quicker to unexpected events during fog conditions, the VES itself did not effectively replicate a real VES. As mentioned previously, a VES displays thermal energy differences between objects and their backgrounds. The simulated VES, tested by Nilsson and Alm (1996), was simply a black and white image of a clear visibility drive placed on a fog visibility drive. Understandably, if all critical objects appeared in this black and white image, then reaction times and speed selection would be comparable to a colour clear visibility version. Speed and lateral position variation were, however, highest when the simulated VES was used. The novice use of the VES system may have introduced variability in participant's lateral position. Eliminating high-contrast peripheral images, with simulated VES, may have reduced visual flow. Drivers may have increased their speed because they relied on ambient visual information which is a similar response to driving in fog (Moray, 1976).

Nilsson and Alm (1996) also assessed the mental workload of the 24 participants using the NASA-TLX (Hart and Staveland, 1988). The participants reported lower mental and physical demands while driving in fog with the VES than without the system. Effort and frustration subscales were higher for driving with the vision enhancement display. Vision enhancement seems to reduce mental and physical demands, while increasing perceived effort and frustration. Given the preliminary indication that mental workload differences were found between VES and non-VES conditions, follow-up tests were not performed nor was an adequate explanation for this result provided.

Nilsson and Alm (1996) noted, from scrutinizing unexpected event responses, that participants used different strategies in interacting with the VES. Those who responded faster (M = 0.76 s) were deemed to have been using the system extensively, while others who responded slower (M = 1.25 s) were thought to be uncertain about how to divide attention between the vision enhancement display and the external environment. The inability of drivers to divide attention appropriately was identified as a potential risk factor that would make the driving task more complicated.

Ward et al. (1996) tested gap acceptance and time-to-coincidence (TTC) judgments in a lab environment using videotaped thermal images taken from a far (8 to 13 μ) infrared sensor. Gap acceptence was taken to mean, "will my vehicle fit through this gap?," rather than, "is this gap in traffic large enough for me to pull out safely?", which is the more common meaning. The thermal images were in both black-hot and white-hot formats. Sixteen participants, 8 male and 8 female, evenly selected from two age groups (under 25 and above 55), participated in the study. Two types of night driving scenarios (gap acceptance and TTC, which are described below) were videotaped simultaneously with visible light and infrared cameras. The participants were seated inside a car and the videos were displayed on a projection screen that presented a 25.5˚ vertical by 38.2˚ horizontal view. The researchers do not state if a similar type of car had been used for the videotaping.

The gap acceptance scenarios videotaped an automobile's approach to two foam obstacles that were separated by five varied distances, ranging from 200 mm greater than the width of the car to 200 mm less than the width of the car. The middle three distances were +100 mm, 0 mm, and -100 mm. Therefore, the car would be able to pass through the obstacles at +100 mm and +200 mm distances and would strike the foam obstacles at other distances. The videos were recorded at two approach speeds: 20 mph and 40 mph. The participant was asked to press the brake if the gap was judged to be too small for the car to fit through the obstacles, and to press the accelerator if the gap was judged to be adequate.

Driver responses with infrared images showed a greater number of correct rejections than with normal nighttime viewing. In other words, drivers were more able to respond accurately to gaps that were of inadequate size with the VES than without. Correct acceptances were, however, higher with normal viewing. This suggests that drivers were more able to respond accurately to gaps of adequate size with normal viewing than with the VES. Ward et al. (1996) hypothesized that drivers became more conservative with their decision criteria when using the VES. When the data were pooled from the two age groups, the decision criteria were found to be twice as conservative with the VES than without. Analyzing only the correct responses, Ward et al. (1996) found that driver reaction time was significantly faster with the VES than without, especially for the extreme sized gaps (+200 mm and -200 mm).

The second scenario was videotaped by driving the test vehicle by (i.e., passed on one side) a stationary vehicle. These approaches were videotaped at 20, 30, and 40 mph. The participant was shown these approaches (twice) in random order and at 1, 2, and 3 seconds (corresponding to the three speeds) before the pass a black screen occluded the participant's view. The task was to press the brake when the contact was perceived.

For TTC judgments, the type of infrared image (black-hot or white-hot) made a significant difference. Mean TTC error was higher with white-hot images than both black-hot and normal viewing. As the occlusion period increased, so did response error, ranging from 0.5 seconds at 1 second to 1.39 seconds at 3 seconds, which is consistent with the underestimation of TTC (see, e.g., Caird and Hancock, 1994). Judgments also significantly differed with speed, as higher speeds yielded more accurate results.

Bossi et al. (1997) tested the effect of a VES located in the foveal area of the driver's vision on detection of objects in the periphery. They took a daytime drive video segment and superimposed Landolt C's at various eccentricities (10° to 25° at 5° increments) on both sides of the foveal center of a driver's fixation. These C's formed peripheral targets that were to be detected by 13 (6 male and 7 female) participants. Each target was presented for 200 milliseconds. The segment was degraded to simulate dusk and nighttime driving. To simulate a VES, a daytime 15° x 10° centre image was superimposed on degraded segments.

Participants were asked to track a laser pointer, attached to a steering wheel, at the rear license plate of a leading car which was present throughout the test. This task simulated the primary tracking task in driving. The secondary task was to press the brake when a Landolt C was seen (i.e., detection) and to respond verbally to the randomly presented one of four orientations of the Landolt C (i.e., identification) of the target. Four conditions were tested: night driving, dusk driving, night with simulated VES, and dusk with simulated VES.

Results showed that the night with simulated VES condition had the fewest number of targets detected and identified at all target eccentricity levels (i.e., 10°, 15°, 20°, and 25° on both sides outside of the VES image). The number of targets identified and detected was consistently and significantly higher without the VES than with the VES in nighttime driving. No such difference was found for dusk conditions. More central targets (i.e., 10° and 15°) had greater decrements with night VES when compared to decrements of periphery targets greater than 20°. Night responses were in general° poorer than dusk conditions, regardless of whether a VES was used.

These results reveal the adverse effect of an infrared VES on detection/identification of periphery targets in nighttime driving. As more central targets were detected to a lesser degree than more periphery targets, this suggests that the simulated VES's increased brightness (as it was taken out of daytime driving) tended to reduce the contrast of near peripheral targets.

5.3 Prototype Infrared VES Field Tests

Two European research institutions have field tested prototype VES. They are the Lund University in Sweden (Ståhl et al., 1994) and the HUSAT Research Institute at the Loughborough University in Leics, UK (Ward et al., 1994).

Ståhl et al. (1994) tested a VES for Jaguar with their near infrared technology. The colourized thermal image provided a field of view of 17.6° vertical and 12.8° horizontal. The image was projected on a flat pane of glass placed below the windshield. Automobile windshields are curved and projection on them distorts the image. Correction of distortions algorithmically in real time is a design challenge that will need to be addressed by manufacturers.

Fifteen elderly drivers (11 male and 4 female), who ranged in age from 65 to 80 years, drove on a 1.1 km airfield track twice, once with a VES and once without. The order of use was counterbalanced. Drivers were asked to make a verbal response when they saw particular objects on the side of the track. The objects were dummies of an adult and a child, a large road sign, a small road sign and a set of traffic cones. A technical or phenomenological description of what the thermal object images looked like in the VES was not given.

The location at which the participant verbalized a response was recorded by an observer seated inside the car. The observer noted a number which corresponded to markers placed 25 m apart along the roadway. If the verbal response was made at any point between the markers then the location was recorded as midway between two markers. It is not mentioned whether objects were presented in a different location and order from trial 1 to trial 2.

The dummies were seen earlier with the VES than without by 13 of the 15 participants, with mean earlier responses of 48 m for the adult dummy, and 63 m for the child dummy. The earlier detection/recognition of the dummies ranged from 12.5 m to 112.5 m sooner with the VES. Eight of the 15 drivers saw the cones sooner, with mean earlier responses of 19 m, ranging from 12.5 to 87.5 m. The range of improvements were only provided for drivers who responded sooner with the VES, and not for those who noticed the objects sooner without the VES. An improvement of 12.5 m means that the earlier detection was at a point that could be any location between two markers placed 25 m apart. Traffic sign identification performance was more equivocal. Ståhl et al. (1994) stated that if a standard road sign shape had been used, then different distance results would have been found. No indication had been made that a non-standard sign shape was being used.

A test was also performed on the visibility of a live pedestrian standing 100 m ahead of the car equipped with the VES. The participant was seated in a stationary car looking forward through the windshield. The test was performed first with low beam headlights, then with high beam headlights and finally with low beam + VES system. It is not clear if the order of this testing procedure was counterbalanced between participants. Thirteen of 15 participants could see the pedestrian with the VES, 11 with the high beam headlights and none with low beam headlights.

Most of the participants reported that the system was easy to use and interpret with a few exceptions. The restricted size of the image enhancement was thought to be a problem by some participants. Slightly more than half of the participants responded that they would drive more at night with the system. These included, "all those who failed the eye test" (p. 2006). It is not clear why recruits who had failed the eye test were involved in the study. Only four of the 15, thought the VES would result in increased confidence in driving, and one recognized the perils of overconfidence. All respondents felt safe using the system, but when asked if they would drive with the VES at night "the oldest subject ... thought the enhanced light was too bright and the field of vision too narrow" (Ståhl et al., 1994, p. 2006). Recommended improvements by the participants were widening the FOV and increasing the resolution of the enhanced image.

Ward et al. (1994) field tested a prototype near infrared VES during night time driving conditions with five participants. The VES image was displayed on the driver's windshield using a contact analog monochromatic green HUD, with a field of view of 13˚. It was not indicated whether the FOV of 13˚ was in the horizontal or vertical direction. Ward et al. (1994) mentioned that infrared sensors process thermal energy of a wavelength range of 8 to 13 μ, which is in the far infrared range. They did not identify the range of their "near" infrared sensor or its origins. A Jaguar automobile was used for the test.

Five participants were recruited for the study and provided with one hour of practice with the VES before testing, within a two-week period prior to the experimental field test. In these practice sessions the functioning of the VES was explained and the participant was provided with the opportunity to drive with the VES at night.

A driving route of approximately 1 km, in a rural area, was selected for the field test. Along this road, three pedestrian silhouettes (head and torso) were constructed from plywood material. A large coat was placed on each of the silhouettes. Ward et al. (1994) report that this coat was selected on the basis that it was moderately conspicuous in both normal and VES driving. An operational definition of “moderately conspicuous” was not provided. If VES detect thermal energy differences between pedestrians and their backgrounds, then a pedestrian dummy should, for the test to be valid, emit thermal energy that is similar to a live person. However, this information is not mentioned. Each participant drove the route 20 times, 10 times in each direction. All tests were performed during nighttime conditions.

The driver's task was to identify the side of the road at which the pedestrian was standing, by manipulating a washer/wiper switch located near the steering wheel. Silhouettes were randomly presented along the 1 km route. Some of the silhouettes were stood up during a drive and others were presented during other passes. However, from the description provided by Ward et al. (1994), it was not possible to determine whether the three locations of the silhouettes was randomized. Two of the silhouettes were placed on one side of the roadway (right or left), and the third was placed on the other. At the start of the 17th drive, the VES was shut down to simulate failure.

Mean speed was calculated using the time required to complete travel through the route. As the number of trials rose from the first to the 20th so did the speed for both driving with and without the VES. Thus, as the participants became more familiar with the route and the VES, they drove faster. In contrast to Nilsson and Alm (1996) findings of increased speed selection with a simulated VES than without (during simulated fog conditions), Ward et al. (1994) found a significant reduction in vehicle speed when using the field VES as compared to without it (during nighttime driving). Speed variability was significantly higher when using the VES, which is similar to Nilsson and Alm's (1996) results. Reaction time to the appearance of pedestrian silhouettes was not significantly different between VES and non-VES tests. Driver speed for the simulated failure of the VES did not differ from speed during functioning VES drives.

Mental workload (NASA-TLX) was assessed at five times in the study: after the first, fifth, tenth, seventeenth (i.e., the simulated failure), and the twentieth runs. Overall NASA-TLX scores showed significantly higher levels of mental workload when using the VES than driving without the VES. Overall mental workload scores did not significantly change across trials. Of the six NASA-TLX subscales, mental effort and mental demand indicated a difference between VES and non-VES conditions, with higher scores reported for the VES condition. This suggests that participants experienced greater mental effort and demand with the VES than without. The overall mental workload scores were not significantly effected by the simulated system failure.

A significant difference in pedestrian silhouette detection times was not found between drives with and without the VES. No further analysis or interpretation was provided. It is equivocal how the system failure was involved in pedestrian detection as analysis was only centered around speed and mental workload.

While the Ward et al. study (1994) was "preliminary", it suffers from numerous design weaknesses. In particular, a sample size of five participants is rather small to make strong conclusions. This is especially so when making comparisons between conditions on mean speed, speed variation and overall mental workload. One hour of training does not necessarily ensure that drivers are familiar with a VES. Base levels of perception response time were not reported. The three pedestrian silhouettes were placed in the same location throughout the 20 drive-bys, which would allow the driver to anticipate the appearance of the silhouettes.

5.4 Ultraviolet Headlamp Field Tests

Ståhl et al. (1994) tested an UV headlight system for Volvo, developed by Ultralux AB. Thirty-one older drivers, approximately divided into three age groups: 65-69, 70-74 and 75+, drove on a test track twice, once with standard low beam headlamps and once with UV headlamps. The track was equipped with road markings, posts, barriers and traffic islands that had UV sensitive fluorescent pigment in them. The task of participants was to notify an experimenter, who was seated in the car, when they saw a curve in the roadway, a traffic island, or a pedestrian. The distance from which the objects were seen was calculated by the experimenter by counting the number of poles to the object. These poles had been placed along the track at 50 m intervals.

The results showed that visibility for both roadway structures and pedestrians increased for all age groups with the UV headlamps. The difference in the distance at which roadway structures and pedestrians were visible was largest for the youngest group (65-69 years). When asked to judge forward visibility provided by the two types of headlamps, all age groups chose the UV headlamps as providing more visibility than the low beam headlamps. Ståhl et al. (1994) also asked the participants to rate perceived levels of glare with the UV headlamps. When seen through the rear-view mirror they produced more glare than ordinary low beam headlamps. Participants also judged glare by standing on the roadway as pedestrians. They reported less glare with the UV headlamps than with ordinary low beam headlamps. The inconsistency between more UV mirror glare, but less glare for pedestrians was not addressed.

The results from the older sample were compared to a group of younger drivers (26-60 years) from a prior experiment. In most cases, the older drivers responded more favorably towards the UV headlamps than did the younger drivers.

Fast (1994), a researcher at Volvo and CEO of Ultralux AB, also tested the use of UV headlamps in Sweden on public roads. Road markings had been treated with fluorescent pigments. Drivers were asked to complete questionnaires that asked about visibility of road structures and perceptions about the UV headlamps at the completion of a test drive. Higher visibility of road structures was reported for the UV headlamps than low beam headlights, for rural, urban, dry and wet road conditions. Drivers estimated that their range of visibility increased, especially for rural roads with less street lighting. No negative comments or distractions in using the UV headlamps were reported.

The detection benefits afforded by UV headlamps have been replicated by U.S. researchers (Mahach et al., 1997; Turner, Nitzburg, and Knoblauch, 1997). In a preliminary evaluation, 36 participants (7 males and 8 females above 65, and 13 males and 8 females aged 25 to 45) were asked to evaluate visibility of three different types of pavement markings (Mahach et al., 1997). The three markings were: new thermoplastic with fluorescent material, new thermoplastic without fluorescent material, and old worn and faded white paint. Two types of headlamps were tested: low beam and low beam with UV lighting.

The participants, seated in the passenger seat of a vehicle, were asked to rate how well the markings indicated where to drive the car within a lane, while the vehicle was being driven on a stretch of road. The order of headlamp use and type of markings was counterbalanced among participants. Subjective visibility ratings of fluorescent pavement markings with UV headlamps were significantly higher than for low beam headlamps. There was no difference between UV headlamps and low beam headlights for new thermoplastic markings without fluorescent material or with worn and faded white paint. Age and gender analyses were not reported for the preliminary study (Mahach et al., 1997).

At a static test site, participants were then asked to rate the overall visibility of road markings while they were seated inside the test car with the UV headlamps. Participants counted the number of centerline dashed markings that were visible to indicate the outer bound of illumination provided by the two headlamp types. The visibility tests were performed first with low beam headlights and then with UV headlamps. Subjective ratings of visibility and the number of center dashed lines were significantly higher for UV headlamps than for low beam headlamps. Age and gender results were not given (Mahach et al., 1997).

Following these preliminary tests, another group of participants drove on a 1.6 km training track and an adjacent 0.8 km stretch of access road to the track, both of which had been equipped with fluorescent markings. A 1994 Ford Taurus was outfitted with European UV headlamps (from Ultralux AB) and American low beams with UV (origin not mentioned) and conventional low beam headlamps.

Twenty-eight participants (8 were between 16-25 years, 14 were between 25 to 59, and 6 were older than the age of 60) volunteered for the study. Objects were placed on the track, and participants seated in the front passenger position were asked to say when they were able to detect and identify objects seen through a shutter placed on the windshield. The experimenter drove the test vehicle toward the objects from a starting distance exceeding 270 m. The shutter would open for two seconds at incremental distances (30.5 m) in approach to the objects. If the participant saw the object during the two seconds that the shutter was open, then the distance from the object was recorded as the detection distance. The car was driven toward the object until the participant had also recognized the object correctly. This recognition distance was also recorded.

The first set of objects were three pavement markings: no passing zone, right curve, and pedestrian crosswalk. Mean detection and recognition responses were further away with UV headlamps than with low beam lights. No passing zone and pedestrian crosswalk markings were significantly different, favoring the UV headlamps. Age and gender differences were not mentioned (Turner et al., 1997).

The second set of objects were pedestrian plywood silhouettes that were dressed up in everyday clothing that had been washed once in detergent. The three plywood pedestrians were a small child riding a fluorescent bicycle, an adult walker, and a jogger. All were placed so that they would seem to be on the roadway. Detection and recognition distances were significantly higher with UV headlamps for all objects, except for the adult silhouettes.

Finally, a live pedestrian walked onto the roadway, from behind a car with low beam headlamps that were facing the participant's vehicle. Participants were told that a live pedestrian may or may not enter the roadway during the testing. Mean detection and recognition distances were higher with UV headlamps than with low beam headlights.

A test, similar to the preliminary study, was also performed. Participants drove around the track four times, once with U.S. regulated low beams, U.S. low beams with UV, European low beams and European UV headlamps. As in the preliminary study, the UV headlamps were subjectively rated higher, on visibility and distance illuminated, than low beam lights. Interestingly, European low beam lights were rated higher than U.S. UV headlamps and low beam lights. Performance measures (speed and lateral position variations) from the driving tests were as yet unavailable and were being analyzed (Turner, et al., 1997). Results categorized by age and gender of the participants have not yet been reported by Mahach et al. (1997) and Turner, Nitzburg, and Knoblauch (1997).

5.5 Summary

The essential issues of IVES and UVES are the degree that older drivers are able to detect and use system information to control their vehicles' safely. The above review has reported that both types of systems are in development and have entered preliminary evaluation phases. While these systems may aid older drivers during nighttime driving conditions, unequivocal, convergent, experimental results are as yet unavailable. Human factors professionals have recognized VES as important application and appropriate assessment of safety is critical (Lunenfeld and Stephens, 1991).

Researchers have not paid attention to training issues (e.g., one hour of practice before testing by Ward et al., 1994) or what the proposed infrared detectors are supposed to look like (e.g., taking a daytime video and using it as a thermal image VES by Nilsson and Alm, 1996). Current HUDs can only afford a restricted view in which the forward looking IVES can be displayed. This range would necessarily need to be expanded. If the focus is on reducing older driver accidents with pedestrians at nighttime, then an augmentation of objects at the center of the road will not suffice. Improvements to driver views to the side of the car, at the edges of the roadway, would be, theoretically, more beneficial. Moreover, if VES HUDs are to be used in a contact analog fashion, then to what degree does image brightness affect the driver's ability to not only see the object but also notice other critical information not in the HUD. These are serious issues that need to be addressed by future research before attempting to make generalizations on how real-world use will affect driver speed selection and other behaviours. As product developers are focusing on making the sensors as inexpensive as possible for wider marketing and use, the onus is on researchers not only to evaluate these new products but to do it in a manner that contributes reliable (generalizable) results. Specific to older driver issues, a comprehensive empirical study with an established viable VES prototype has not yet been undertaken.

In conclusion, the infrared VES appear to be a tool that will afford drivers the ability to see low contrast (live) objects better, which will subsequently reduce nighttime pedestrian accidents. Low-contrast objects may become more detectable, but the problem of recognition of these objects will remain. In other words, how is a child's heat image, once seen, recognized as being a child, and even further, recognized as being in the roadway and thus to be avoided. This problem can only be worsened if the collimation of the heat image is not at the same focal distance as the object it augments.

Ultraviolet VES have received extensive research efforts from both European and U.S. based teams. UVA headlamps do not appear to be harmful to the eyes of persons outside the vehicle. They also benefit from the fact that while pedestrian clothes naturally have fluorescent elements in them, other roadway objects (e.g., trees and other vehicles) do not. This seems to be a benefit for older drivers who have difficulty detecting low contrasts objects at nighttime. How will older drivers perform with the UVES system in the presence of glare from either conventional or UV headlamps? Strong empirical results for older drivers with UV headlamps have as yet not been reported. It is essential that this be done before acceptance is endorsed. Roadway markings and posts can be produced with fluorescence if the focus is on illuminating them, in an attempt to reduce single vehicle run-off-the-road accidents. In conclusion, UVA headlamps also appear to be tools that can afford increased visibility further down the roadway and for low contrast objects. The concern for eye damage to persons outside the vehicle, from long-term exposure to the headlamps, still remains. This has not yet been resolved.

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6.0 HUMAN FACTORS GUIDELINES FOR OLDER DRIVERS AND VISION ENHANCEMENT SYSTEMS (VES)

> *Design, on the other hand, is concerned with how things ought to be, with devising artifacts to attain goals* (Simon, 1996, p. 114).

Human factors guidelines typically specify ways that designs should consider the user. For many reasons in the process of designing, the user is often forgotten. Guidelines are helpful as a check so that applications do not forget to consider important user requirements. A guideline is useful if it solves a design problem.

Previous ergonomic guidelines developed for use with aviation displays were not necessarily created with ITS applications in mind (see, e.g., Stokes, Wickens, and Kite, 1990; Weintraub and Ensing, 1992). The control tasks and the constraints imposed by traffic environments are fundamentally different from those in aviation. While some human factors design guidelines for ITS in-vehicle applications have been extended from other areas of transportation ergonomics, human computer interaction, design experience, and experimental psychology, many that specifically consider the traffic context and the integration of application tasks with driving still require further development.

The Federal Highway Administration (FHWA) in the U.S. has had a number of research groups produce design guidelines for Advanced Traveler Information Systems (ATIS). Similarly, the National Highway Traffic and Safety Administration (NHTSA) supported the development of guidelines for collision avoidance systems (CAS) (Mast, 1995). Products developed in the FHWA human factors program include: 1) human factors guidelines and handbooks, 2) human factors databases so that computer searches can be conducted to identify data relevant to particular research and design questions, and 3) human factors performance models to allow users to predict driver performance. These information products are being developed to aid the design of ITS applications to meet drivers' needs and requirements (Mast, 1995).

While guidelines have been developed for use in a number of ITS applications such as ATIS/CVO and CAS, VES guidelines have received much less attention. Those that apply to VES are often too general to be of significant guidance (see Appendix A). In addition, existing ITS design guidelines do not necessarily accommodate older drivers' performance limitations and preferences. Those collected by NHTSA, the FHWA, and others require careful analysis and, in many cases, modifications to individual guidelines are necessary to achieve an appropriate fit to older drivers' capabilities.

Published technical reports, journal articles, and conference proceedings produced by U.S. and European transportation agencies served as primary information sources for guidelines considered for this project (see, e.g., Clarke et al., 1996; Dingus et al., 1996; Green et al, 1995; Landau et al., 1998; Nicolle and Stapleton, 1995). Literature sources on aging were also consulted, especially where information could be used to specify older driver visual requirements (Granda et al., 1997; Kline and Scialfa, 1997; Vanderheiden, 1997).

Design principles and general guidelines that address VES and/or older drivers are considered in this report (see Appendix A). System-specific guidelines and function integration guidelines are beyond the scope of this report as are speech, auditory, and auditory-visual interaction guidelines. We have erred on the side of inclusion of extra guidelines from a variety of sources. As a result, many of the guidelines in Appendix A may aid in the development of related system functionality. By erring on the side of inclusion, however, a longer search might be required. To make Appendix A more usable, guidelines that were thought by our research team to be highly relevant to the design of VES systems are marked with an * (asterisk). Guidelines specific to older drivers are expanded somewhat in Sections 6.3 (Design Principles) and 6.4 (General Guidelines).

6.1 Guideline Definitions

Guidelines are part art and part science, and not necessarily in equal ratios. Guidelines serve a number of functions including as a means to summarize human engineering data, to make general recommendations about design, and to specify design principles (Cambell, 1996). Guidelines have a number of important properties that allow them to be more or less useful. The intent of a guideline is to put human factors knowledge into a form that can be immediately used by designers. Human factors guidelines must be well organized, readable, and apply to design problems to be useful. A guideline that includes domain context is accessible and provides a foundation on which to extend a new design is likely to be more useful and usable (see, e.g., Burns et al., 1997; Green, 1995).

A guideline may be derived from the design constraints of a class of problems, the available empirical information in a particular domain, from a specification for user requirements, and from expert judgment. Expert judgment, if acquired, tends to take over where guidelines and user requirements are limited or unclear.

In our search of relevant sources, the overlap of guidelines between sources varied somewhat. Many guidelines do not provide adequate convergent empirical support or original reference information. For example, "the guidelines that were reviewed uniformly lacked the appropriate supporting data necessary to specify driver-vehicle interface guidelines" (Landau et al., 1998, p. 441). Guideline consensus is achieved when multiple empirical sources are unequivocal. Empirical studies are rarely replicated and the results of studies are typically not put in a form that can be used by designers. If a guideline, or variations on it, have been listed by several guideline sources, it might be important or it might have been repeated by a number of authors without questioning the empirical basis of it.

ITS standards, in contrast to guidelines, represent the best practice and state of the art for a given technology. A potential standard must achieve consensus among diverse vested interests in the arena of SAE or ISO. Parkes (1997) lists three types of potential ITS standards: product, performance, and procedural standards. Product standards specify how a product ought to be in form (e.g., shape, colour, or dimensionality). Performance standards define how a distribution of drivers and a product ought to perform when used (e.g., the time necessary to acquire information from a display). Procedural standards prescribe a program of analysis and testing to determine the safety and efficacy of the product through the design cycle. The latter, or procedural standard, is aligned with the objectives of this report, namely, to specify existing guidelines and evaluation methods that are applicable to VES and older drivers. Each of these standard types has advantages and disadvantages (Parkes, 1997).

A number of U.S. Department of Transportation (DOT) motor vehicle safety standards are applicable to in-vehicle ITS; for example, Standard No. 101 applies to controls and displays (see U.S. DOT 49 CFR Part 571). In addition, SAE document J1606 Mar93 *Headlamp Design Guidelines for Mature Drivers* provides information for the design of headlamps which is important to the development of UVES (also see Waller and Green, 1997, pp. 2001–2004). No standards for ITS applications have been established to date (Fleishman and Dingus, 1998).

The International Organization for Standardization TC22 (Road Vehicles), SC 13 (Ergonomics Applicable to Road Vehicles), W08 (Traffic Informatics Control Systems on Board—MMI) has as first priorities: requirements for visual information presentation and visual demand measurement methods (Parkes, 1997, pp. 401-402). Secondary priorities of this working group include principles for choice of information presentation mode and evaluation methods. These priorities are highlighted from a larger set because they are integral to the objectives of this report.

A variety of other information sources can be useful. Literature reviews, in contrast to design guidelines and standards, are useful for obtaining an overview of a particular research area. Reviews, in order to determine the research and development status of a product, must consider preliminary data from technical reports and conference proceedings as a means to identify important independent and dependent variables (e.g., Section 5 on VES). These intermediary data sources should be reviewed with an eye for experimental design quality and the plausibility of conclusions. Reviews that focus on research methods can provide insight into ways to evaluate systems.

6.2 Development of Human Factors Design Guidelines

Several approaches to derive ITS design guidelines were found in the ITS human factors literature. In the first more typical approach, a variety of source materials such as handbooks, technical reports, conference proceedings, book chapters, and journal papers is reviewed. A body of guidelines is then derived and appropriately organized and formatted (see, e.g., Dingus et al., 1996; Landau et al., 1998; Nicolle and Stapleton, 1995). For example, Nicolle and Stapleton (1995) organized their guidelines for older and disabled drivers into sections for general principles, control of the system, display of information, training, and documentation. This approach assumes that it is possible to specify, before the creation of a specific application, a comprehensive body of knowledge that will be useful to designers.

In contrast, Green et al. (1995) advocate documenting the critical issues that designers resolve so that others who traverse similar design paths can quickly move past the same difficulties. Understanding the design issue and how it was resolved is fundamental to creating better design guidelines (Green et al., 1995). These types of guidelines, in theory, may inform better designs. This process assumes, however, that guidelines derived from design issues will be frequently encountered.

Pragmatically, guidelines are intended to quickly get the designer or engineer part of the way to a solution. The remainder of the path is left to the designer and design team. Human factors design decisions are likely to include the expertise of the individual, the literature, and immediate colleagues to make real system decisions (Rouse and Boff, 1998). The process of design is, in part, proving or confirming from a set of possibilities, options that may make a product viable. Guidelines can serve to constrain a solution space and eliminate design paths that are not viable (Simon, 1996).

Few studies have examined how designers actually use human factors knowledge in context. In a rare set of studies, Burns et al. (1997) examined how students and professional designers used information from the *Engineering Data Compendium* (EDC) (Boff and Lincoln, 1988) and the *Human Factors Design Handbook* (Woodson et al., 1992) (HFDH). In the first experiment, the two handbooks were directly compared by asking groups of undergraduate engineering students with no HF design experience, undergraduate engineering students with HF experience, and professional systems designers, to answer four design questions using the two books. Fourteen participants were in each group and half were randomly assigned to one design handbook or the other. The HFDH, perhaps by virtue of being 1,674 pages shorter, took a mean of 21.1 steps (7.1 min) to answer a design question, versus 23.9 steps (10.5 min) for the EDC. In particular, questions about the limits of working memory and hand-operated input devices were facilitated by the length and/or organization of the HFDH. Complaints about both handbooks centered on information not being specific enough or not providing sufficient context to help solve design problems.

In a second experiment, 18 professional HF engineers in the nuclear power industry were presented with information from the EDC. In addition, thirty-five questions organized into seven major topic areas were rated on the dimensions of cost, importance, relevance, and effort. Cost to obtain the information was rated high, whereas effort to obtain the information was low. Importance and relevance were rated relatively low. Some information in the EDC was relevant to design problems, whereas other information was not particularly useful. Information that is contained in the form of guidelines must be easy to obtain and of relevance to designers. Thus, quick access to useful information that solves design problems is an essential attribute of guidelines (Vicente et al., 1998).

6.3 Design Principles

General design principles encompass many aspects of the practice of human factors engineering itself. A design principle is conventional wisdom which often governs the ordinary practice of the discipline of human factors (Green et al., 1995). For example, design principles listed in Appendix A were thought to be essential to everyday practice. Guidelines can also apply to particular product attributes such as the colour of a display window. The relationships between design principles, general guidelines, and specific guidelines are illustrated in Figure 6.1 (Green et al., 1995). Design principles, because they encompass general and specific guidelines, are illustrated as such. Inputs and outputs, which comprise large sections in Appendix A, are covered by general guidelines.

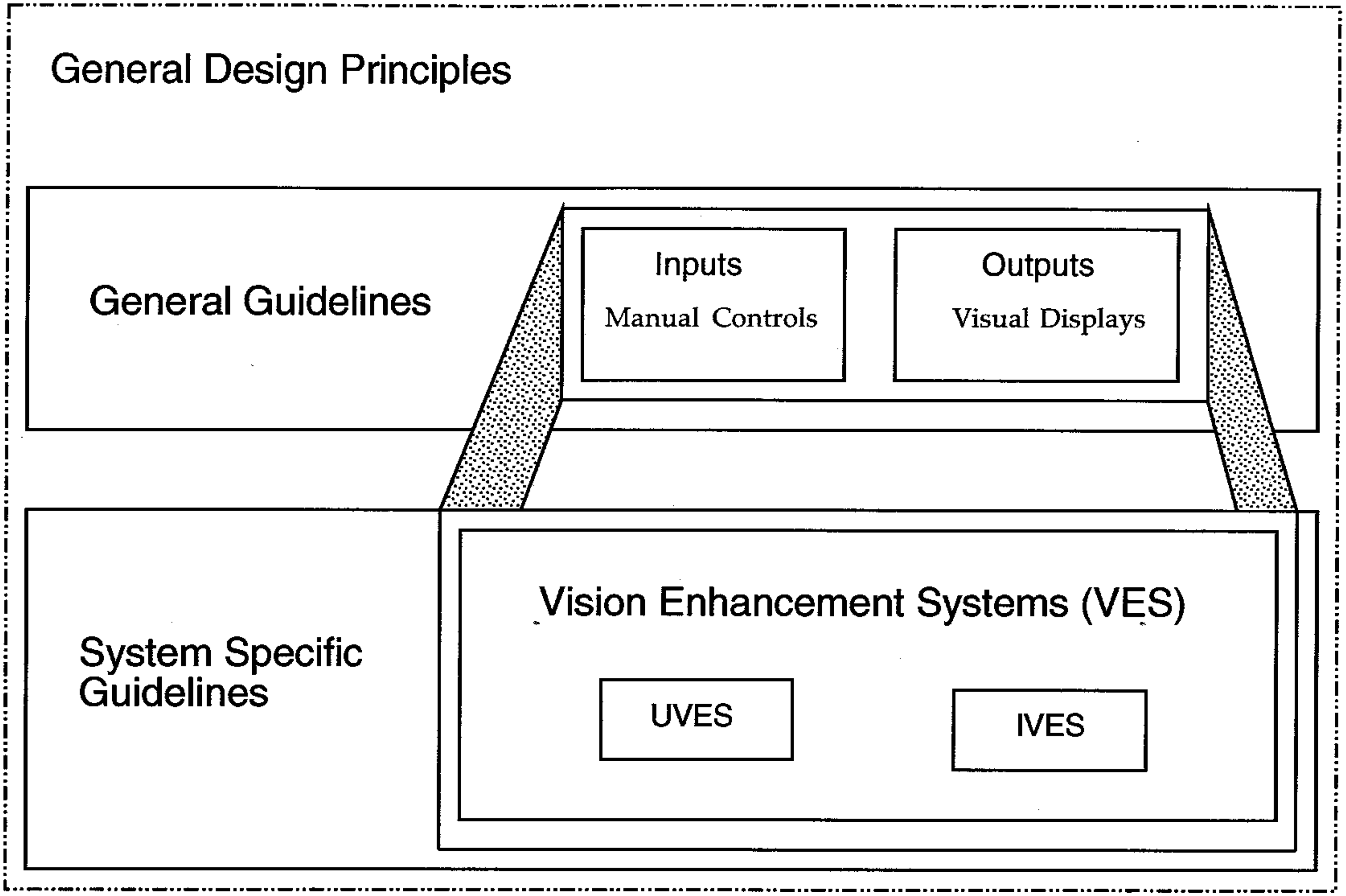

Figure 6.1 The relationship of design principles, general guidelines, and system-specific guidelines for vision enhancement systems (VES). Adapted from Green et al. (1995, Figure 1, p. 8).

On the basis of our literature review on older drivers (Section 4), a number of additional design principles were derived and are listed below:

- Fundamentally, human factors contributions to in-vehicle transportation systems must advocate designs that accommodate a large distribution of users, especially older drivers, a wide range of ambient lighting conditions, and minimize workload.

- Contrary to popular belief, guidelines that seek to optimize a design for an older driver, may not necessarily accommodate younger drivers. These groups often differ on the reasons that they drive.

- Higher levels of task difficulty that impact working memory, division of attention, or manual control are more likely to affect older drivers than younger drivers.

- ITS applications that produce divided attention between tasks, redirect attention for prolonged periods (multiple looks and looking) or extreme oscillations in mental workload (overload and underload) are likely to endanger those exposed.

- It is naive to believe that drivers will not interact with in-vehicle displays while encountering potentially dangerous traffic situations, unless constrained by design not to. Allocation of ITS functions to "when driving" and "while stopped" may encourage drivers to stop in hazardous locations (e.g., railway tracks) to use an application (e.g., mobile phone or Web browser).

- The fit of an ITS application such as VES to older drivers must consider the behavioural adaptations that may have already been made by drivers. Congruence between driver limitations, an ITS application, and existing behavioural compensations should be sought.

6.4 General Guidelines

General guidelines typically specify the format of user inputs (e.g., manual controls) and outputs (e.g., visual displays). The fit of older driver capabilities to adaptations of the environment and technology are essential considerations of general guidelines. For example, adaptations of the traffic system so that the largest distribution of users are accommodated is fundamental. An older driver would be considered disabled if he/she could not accommodate to a vehicle or the traffic environment as it is currently designed (Vanderheiden, 1997). To accommodate, driver responses can change, the vehicle (a mobility tool) can be adapted, or the traffic environment can be modified. Recall that behavioural compensation to technology, declines in driver ability and changes to roadways were considered in Sections 3.5 and 4.5. IVES represents a vehicle adaptation, whereas UVES is a modification of the vehicle (ultraviolet headlamps) and the roadway (luminescent material). For both IVES and UVES, the motorist must be taught how to use these vehicle enhancements (also see Section 4.6, ITS and the Older Driver).

The purpose of IVES is to enhance objects that have heat (e.g., animals and humans) and UVES to enhance road lines so that lane keeping in a variety of conditions is made easier (see Section 5). Forward looking IVES will likely be implemented in a HUD format. Thus, guidelines which constrain HUDs are important to IVES (see, e.g., Gish and Staplin, 1995, and Attention, Workload and Safety, Appendix A). If IVES are used to look to the sides of the vehicle for the presence of other vehicles, objects, and pedestrians, the guidelines that apply to auditory warnings are applicable (see, e.g., Landau et al., 1998, Table 13.10, p. 422). Auditory warning guidelines are not addressed in this review. When IR systems are used for side and backing detection, the system is for practical purposes a collision system. Then collision avoidance system guidelines apply (see, e.g., Lerner et al., 1993).

- The use of colour within an IVES is a critical design decision because of the range of ambient lighting conditions under which it must function. A wrong colour choice or a display that lacks redundant information will affect those with colour deficiency.

- Controls for UVES systems are likely to be integrated into the stalk beside the steering column where the lights of a vehicle are usually operated (see Waller and Green, 1997; and Wierwille and McFarlane 1993 for specific movement conventions). Being able to turn the UV headlights on and off quickly when other vehicles approach should be a design priority.

- Feedback is crucial for older drivers to make changes to their driving that improve safety.

- Selecting a display with hard to see characters and symbols for someone with visual difficulties is a poor design choice.

6.5 Critical Human Factors Design Issues

Human factors guidelines should facilitate good design decisions. Specific context-dependent human factors knowledge and guidelines available at the right time are helpful. The following questions were raised as ITS guidelines were reviewed:

- When are human factors guidelines needed in the design process?
- Are certain forms of media more effective at reducing guideline search cost (e.g., Web, CD-ROM, database, etc.)?
- What human factors data sources are typically used by ITS designers?
- How can human factors guidelines be made more relevant to designers?
- Can specific guidance accompany guidelines that constrain how, when, and where certain guidelines apply?

Guidelines that address the integration of manual controls and displays into ITS in-vehicle applications are few in number. Guideline creators must anticipate what ITS information will be useful before detailed design specifications are known. Transforming human factors guidelines into information that properly considers older drivers is a difficult process.

Many guideline sources that have been compiled, such as Dingus et al. (1996), Landau et al. (1998), and Green et al. (1995), were conceived as aids to the development of navigation systems and driver information systems (i.e., ATIS/CVO). When the precise functionality of VES is under-specified or unknown, new guidelines must be generated as design issues are encountered. The systematic efforts and time necessary to accomplish this task may not come to completion until after a set of guidelines can potentially influence design decisions. Thus, guideline creation as conceived by various researchers is a *post hoc* abstraction of knowledge based on research, design experience, and/or literature reviews. Certain ITS applications are likely to be in more advanced phases of development where design guidelines are less likely to have an impact. However, guidelines in later design phases may serve as a checklist to ensure that important human limitations have been considered (i.e., user-centered design, visual limitations, etc.).

6.6 Summary

Human factors design guidelines are meant to put knowledge into a form that is more immediate and is potentially more useful than gold-panning the psychological and engineering literature for small flecks of knowledge. Guidelines must be relevant to the problems designers encounter (Vicente et. al., 1998). Determining what information designers need to solve human-centered design problems has only recently become an important enterprise of human factors (Rouse and Boff, 1998). Other approaches have included putting the sum of human factors knowledge into large compendiums such as the *Engineering Data Compendium* (Boff and Lincoln, 1988) and the *Handbook of Human Factors and Ergonomics* (Salvendy, 1997). Designers must then search for the appropriate topic, determine whether a set of information fits the problem that they are working on, and then translate or extrapolate it into a usable form (Cambell, 1996). This search and transformation may render the information costly and lack of specificity may render it useless. To be useful, ITS design guidelines must meet the requirements of:

- *Accessibility*. Guidelines must be accessible to designers (e.g., on the Web) and easy to search (e.g., through indexes or appropriate query languages).

- *Specificity*. Guidelines must be relevant to decisions that designers make. Often, guidelines are too general. Inclusion of case examples and information about the derivation of a guideline may allow designers to reason by analogy or ascertain the degree that a guideline is generalizable to a specific problem.

- *Context*. The derivation, interpretation, and application of a design guideline must consider the task and environmental context of the driver.

- *Consensus*. The foundation of a guideline should be unequivocal empirical evidence from a number of sources that are cited and open to inspection by the reader.

Standards, in contrast to guidelines, are much harder design constraints. The International Organisation for Standardisation (ISO), the Department of Transportation (DOT, U.S.), Transport Canada, and the Society of Automotive Engineers (SAE) issue standards that designers must adhere to. No standards have been developed for in-vehicle ITS applications to date (Fleishman and Dingus, 1998).

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7.0 EVALUATION METHODS FOR ITS

> *It is not the role of safety research to prescribe what is good for society, but to provide reliable information for more informed choices (Evans, 1991, p. 377).*

7.1 Introduction

One of the charges of this contract was to compile a set of empirical and analytic approaches from cognitive aging, cognitive engineering, human error, human computer interaction, and transportation ergonomics to determine the degree that ITS technology will affect driver safety, product usability, and user acceptance. The underlying assumption of this goal is that the appropriate application of evaluation methods to ITS applications should increase societal benefits and reduce risks to users of those products.

Basic knowledge of driver behaviour and system-specific design experience is lacking (Green, 1995b). Therefore, "[s]pecifying absolute threshold levels of safe and unsafe driving performance is generally not possible at this time" (Green, 1995a, p. 1007). In addition, ITS technologies are changing rapidly and as a result, are difficult to evaluate (Green, 1995a; 1995c). Research on ITS tends to be performed on a contractual basis where replication of previous results is the exception and not the rule. A patchwork of ITS and ITS-related knowledge has been hastily pasted together. Overall, with a few exceptions, a coherent, sequential body of research on ITS human factors is only beginning to emerge.

From a human factors perspective, considerations of ITS are predominately about safety. Ideally, an evaluation method should have the potential to determine whether a particular ITS product will improve safety, have a negligible effect on safety, or in the worst case, reduce safety (see, e.g., Evans, 1985). A variety of measures have been used to estimate the relative safety of ITS applications. "Steering control, lane position, variability, speed or headway maintenance, and eye glance duration and frequency were used as proxies of safety measures" (Zaidel, 1991, p. 31). Worse values of these performance measures are interpreted as being less safe. Reductions in safety can result from changes in driver behaviour (see Sections 3.4 and 4.5). Safety can be compromised by conflicts between: interaction requirements with an ITS application and the demands of the traffic environment; information in the ITS application and traffic controls and signage; and ITS information and the goals of the driver. Positive safety impacts of ITS applications may include appropriate speed choices, appropriate headway adjustments, optimal arousal, improved overtaking and gap acceptance decisions, and reduced extended exposure (Flyte, 1995).

What is acceptable performance in a given situation is often open to the interpretation of the driver and/or experimenter. The difficulty of determining the safety benefits or liabilities for a given ITS application is that human factors methods tend to concentrate on performance measures that do not translate into system level safety measures (Chapanis, 1988; Meister, 1989). Performance measures such as lane variability represent safety proxies where poorer performance is viewed as less desirable and more likely to increase the probability of an accident (Fleishman and Dingus, 1998; Zaidel, 1991). There are no means to link accidents to ITS applications without data. A mapping between accidents and performance, with a multitude of attendant difficulties (see, e.g., Rasmussen, 1990), is required. Acceptable level of safety is specified in terms of accidents and relative safety is open to the subjective interpretation of the likelihood that particular ITS application interactions will dispose the driver to greater or lesser risk.

Safety is affected by how the technology is developed and tested. The relative importance of a variety of measures is not agreed upon (Green, 1995b; Parkes, 1997). The selection, collection, and interpretation of key performance and system safety measures is likely to vary depending on the researcher, the organization for which they work, the ITS application, and available resources. The addition of an ITS application to the transportation system can have unpredictable effects because of collective interactions between drivers (Evans, 1985; Zaidel, 1991). While it is possible to list methods and measures and the relative merits of each, it appears that a definitive assignment of an ITS product to an absolute level of safety is not possible without accumulated evidence over time while the product is used within the transportation system. Some would debate whether absolute safety is ever measurable.

In spite of these difficulties, once designed and prototyped, an ITS in-vehicle application needs to be put through an evaluation process to determine the difficulties that users have with it under a variety of circumstances (e.g., on the road, in emergencies, etc.) and as users integrate its use into the task of driving (Smiley, 1996). Several excellent reviews of measures and methods specific to ITS in-vehicle technology have been published; namely, Green (1995b) and Zaidel (1991). Given the depth, scope and treatment of these reports, only a brief overview will be given. In contrast, the contribution of this report is to highlight a number of complimentary methods and measures to the available approaches previously reviewed and to point to a number of alternative measures. In particular, human error and usability engineering methods are discussed in greater detail. Human error methods are critical to assess safety and usability engineering methods provide a quick, low-cost means to evaluate products.

Methods to test and evaluate ITS in-vehicle displays do not come without explicit or implicit theories of human performance (see, e.g., Card, Moran, and Newell, 1986; Hutchins, 1995a; Lee and Kantowitz, 1998; Meister, 1989; Michon, 1989; 1993; Rasmussen, Petjersen, and Goodstein, 1994; Schiff and Arnone, 1995). If wielded without dogmatic bias, these theories are useful in that they provide prospective means to understand ways in which performance can manifest or be analyzed. Theory can also serve as an able guide in the selection of appropriate measures (Kantowitz, 1992; 1997). Regression into the polemics of which theory is better or worse and the subtle interpretive nuances of each is beyond the scope of this report (however, see, Michon, 1989; Schiff and Arnone, 1995).

7.2 Traffic Safety Revisited

> *"Safety" ... represents behaviours, situations, or conditions that on the basis of traffic safety research and behavioural theory, are associated with either higher or lower probability of accidents* (Zaidel, 1991, p. 22).

Can drivers safely drive with new ITS technologies? Many of the most prominent researchers in transportation human factors have tried to address this issue (see, e.g., Green, 1995b, 1995c; Kantowitz, 1997; Michon, 1993; Noy, 1997a; Parkes, 1997; Ranney and Simmons, 1993; Sheridan, 1993; Smiley, 1996; Zaidel, 1991). Like the expert definitions of safety that were elicited in Section 3.5, differences of opinion are evident and are reviewed next.

The Haddon matrix (1970), in its various forms, has allowed those concerned with traffic safety to categorize the impact of particular interventions. Figure 7.1 is one such adaptation of the matrix. The matrix is a simplified account of intervention approaches. Cells within the matrix represent the intersection of accident contributor (human, vehicle, and environment) with crash phase (pre-crash, crash, and post-crash). ITS applications can be placed in different cells in the matrix. For example, Mayday systems affect the delivery of emergency medical assistance to drivers, which is the intersection of driver and post crash. In contrast, VES information impacts the human in the pre-crash cell.

Taxonomies serve as a categorization theory where certain safety approaches, in this case, are similar to or different than other approaches (Meister, 1989). On closer inspection, classifications may fail because approaches are inherently multidimensional and do not fit exclusively into a single cell. For example, Noy (1997a) notes that it is the *interaction* between humans, vehicles, roadways, and the environment that allow us to understand where costs and benefits of an ITS application can be derived (see, e.g., Noy, 1997a, p. 1020, Table 1; or Zaidel, 1991, p. 23, Table 4.2.1).

Crash-Phase

Accident Contributor	Pre-crash	Crash	Post-crash
Human	Technology Safe behaviours Social norms Legislation	Occupant potection devices Avoidance manoeuvers	Emergency medical services Medicine
Vehicle	Maintenance Safety features	Kinetics Vehicle strength	Extrication Fuel
Environment	Roadway design Traffic control	Weather Other vehicles Fixed objects	Temperature Location Weather
	Accident Reduction	Injury Prevention	Severity Reduction

Safety Approach

Figure 7.1 A matrix of potential safety approaches to reducing the frequency and severity of driver accidents. Model representation adapted from Evans (1991) and Rumar (1985).

To illustrate, VES use either infrared or ultraviolet headlamps to enhance or detect various aspects of the roadway and environment (see Section 5). The driver, however, must be able to perceive the salience of the environment or display information. Thus, the technology (embedded in the vehicle) serves to enhance roadway information (environment) so that the driver (human) may steer the vehicle and avoid obstacles. Certain drivers may behave with the VES such that the benefits of the technology (increased visibility) are negated by driving at a higher speed (behaviour compensation). If a driver chooses a higher speed, they are increasing their mobility at the cost of decreasing safety if a collision were to occur. However, from the perspective of the driver, changes in risk associated with driving faster at night may not be perceptible. More specifically, VES increases the range (distance) and wavelength of visual capabilities, which may allow drivers to anticipate hazards and preview information for vehicular control.

Like the Haddon matrix, Hanowski et al. (1995) developed a taxonomy of safety interventions for older drivers that encompasses nine areas of focus: driver licensing, driver training/counseling, crash worthiness/occupant protection, post crash medical care, behavioural medicine, fitness for duty (FFD), environmental issues, cooperative systems, and vehicle design/crash avoidance. Through a thorough literature review and the use of their taxonomy, the authors were able to identify numerous primary and secondary research needs that have the potential to result in effective older driver safety interventions. For example, because older drivers are three times more likely to be killed in an accident (Evans, 1988), the development of interventions that affect time-critical delivery of emergency medicine and the rehabilitation of injured elderly drivers is clearly important. Other older driver countermeasures are discussed in Section 8.

Reductions in injuries and fatalities previously achieved by engineering and medical approaches are discussed in terms of which approaches may bring about additional safety gains (Evans, 1991, p. 349, Table 13-3). Evans ranks behaviour modification (e.g., social norms and specific behaviours) and technology as having greatest future benefits. Technology is categorized into high and traditional technologies where high technology refers to applications like VES. Traditional technology is defined as including electrical, mechanical, and civil engineering. High technology ranks fourth behind benefits from changing social norms, specific behaviour modifications, and continued use of traditional technology.

Sheridan (1993) discusses four primary safety difficulties that ITS faces. He argues first that congestion increases safety because vehicles travel slower. Reducing congestion is a goal of ITS. Thus, the goals of ITS and safety are in opposition (also see Evans, 1991), which may be part of the initial skepticism of the safety related emphasis of ITS. Second, ITS safety will come through technologies that tend to automate decision making. Drivers, like pilots and nuclear power plant operators, are likely to be poor automation monitors (also see Hancock et al., 1995). Third, the degree that ITS safety gains will be lessened by behaviour compensation is largely unknown. Fourth, drivers, in the face of uncertainty, may choose to trust the computer system that resides in their vehicle which may, in fact, be unreliable. Thus, the reliability of ITS applications is critical. In the extreme case, drivers may choose to abandon control of their vehicles and their safety, because they may believe that the ITS device will take care of the critical situation. Drivers may believe that an ITS application is infallible and does not make mistakes (Sheridan, 1993, p. 27). Given the informational emphasis that ITS technologies have taken, unreliable information is more likely to be a problem than automated vehicular control.

Burgett (1994, p. 499) poses three questions about safety and sets out to determine whether TravTek (i.e., navigation), collision avoidance, and travel aids (i.e., an in-vehicle warning system) are safe. His questions are:

- Do drivers drive more, or less, safely with the system than without it, in ways related to the system?
- Do vehicles equipped with the system have fewer or more collisions than vehicles without the system?
- If all vehicles in the fleet were equipped with the system, would there be a decrease, or increase in the total number of collision and collision-related injuries?

The questions asked by Burgett address individual behaviour, relative ITS safety, and absolute system safety, respectively. Only TravTek had sufficient data to preliminarily analyze the potential safety impact. Questions 2 and 3 could not be answered. A number of insights were gained though. Each system evaluation required a different set of methods. Thus, depending on the ITS application, different methods may be necessary to determine the relative safety of the system. The use of various methodologies, such as extrapolation of collision rates to driver populations based on fleet studies, comes with numerous assumptions and limitations.

When older drivers are considered, safety and mobility should be given simultaneous attention (see, e.g., Evans, 1991; TRB, 1988). A number of trade-offs become evident as the range of driver capabilities and reasons for driving are analyzed using both constructs. Existing reports of the use of ITS by elderly drivers tends to emphasize the positive mobility impact that particular devices might have and not the overall safety impact (e.g., Oxley, 1996; Nicole and Stapleton, 1995). Measures of mobility and safety are complementary. Two questions can be asked; they pertain to mobility and relative safety.

- Does a particular ITS application improve mobility?
- Does a particular ITS application decrease, keep the same, or increase safety?

ITS products must meet some safety criteria to be considered viable in the transportation marketplace. Corporations are not likely to bring an ITS product to market unless it is safe for this reason (Sheridan, 1993). Tort liability may prohibit the mass-market distribution of new ITS consumer products without the assistance of government agencies because the safety impact of such products prior to entering the transportation system is largely unknown (Farber, 1995). Alternatively, governmental intervention may be necessary only where systems have been proven safe but litigation exposure may inhibit its introduction (Sheridan, 1993). Automatic systems, which take control from the driver, present higher liability exposure than systems that present information to the driver and require them to act on it. Whether an ITS product can be found safe prior to the introduction of it on a large scale, is the fundamental issue.

Noy (1997b) describes the ITS measurement problem as one of having adequate data to estimate safety. Accidents are not expressed until long after a system has been introduced into the transportation system. This puts the manufacturer in a liability exposure position and implicates a governmental failure to adequately regulate the safety of the driving public. If an acceptable level of safety cannot be determined until an application enters the transportation system, and relative safety estimates are unreliable, then drivers will be still put at some level of risk. Prospective methods that can estimate relative safety are needed (see, e.g., Sheridan, 1993).

Lack of empirical research tends to force analytic techniques (Kantowitz, 1997). Estimating the safety effects of ITS applications is dependent on the assumptions of the estimator. Rarely are assumptions made explicit. Determining whether an ITS product is safe is not always the concern of a development team, especially if the purpose of the device is not directly related to safety. Given the development stage that many ITS applications are at, safety estimates amount to little more than speculative hopes without grounding in related or applicable empirical evidence.

The limitations of knowledge about ITS safety were reviewed. In particular, lack of empirical data on normative driver behaviour (Green, 1995c), the predictability of system level interactions (Evans, 1985), and the necessity for means to estimate relative safety (Noy, 1997a; Sheridan, 1993), stand out as critical issues. Measurement and methods solutions are discussed in subsequent sections.

7.3 Reviews of Evaluation Measures and Methods

Research that has examined the applicability of methods and measures to ITS technologies is presented. A number of guidelines reviewed in Section 6 and included in Appendix A (pp. A-5–A-6) address general evaluation principles. In particular, ten evaluation principles that provide some guidance to development groups are listed (also see Green, 1995b; Clarke et al., 1996). The procedural specificity of these is lacking, however. For example, methods such as rapid prototyping, usability testing, and driving simulation are recommended, but not described per se. For older drivers, a subject matter expert is recommended such that the needs and capabilities of this user group can be adequately represented throughout the various design phases. For all evaluation methods, whether performed by a government agency, corporate laboratory, or university, human factors engineers with sufficient expertise are essential to conducting appropriate tests (also see, Green 1995c; Meister, 1989; Parkes, 1997). Designers should not be expected to do human factors evaluating, because it is by definition out of their area of expertise. Human factors professionals with sufficient education, job expertise, and professional certification, should do the testing. Similarly, the interpretation and conveyance of test results to other development team members is the role of the human factors engineer. Several guidelines (Appendix A: pp. A-6, numbers 7 and 8) address the measures that are important when testing and evaluations are performed. For example, Clarke et al. (1996) emphasize the measures of effectiveness and performance. While important, how to acquire and interpret the measures and why these are important are not given.

A number of dependent variables have been used within transportation ergonomics. The following list is expanded somewhat from its original source (DRIVE Safety Task Force, 1991) and the discussion of it by Green, (1995b, p. 11, Table 3).

- *Subjective Measures:* structured interviews, verbal protocols, questionnaires, surveys, perceptions of ease of use and satisfaction, subjective mental workload (SWAT, NASA-TLX), critical incident techniques, quality of driving (QOD)
- *Performance Measures*: speed, speed variance, acceleration, deceleration, stereotypical emergency responses, headway, standard deviation of lane position, time to lane crossing, brake reaction time, perception reaction time.
- *Dual Task Performance*: mental workload, primary and secondary performance, errors.
- *Visual Behaviour*: sampling patterns, glance duration, glance frequency.

- *Control Actions:* steering rotation/reversals, pedal actuation, gear selection, speed-accuracy.
- *Psychophysiological*: GSR, EKG, EEG (P300), EOG, Eye Blink Rate, EMG, HR, HR variability (sinus arrhythmia), SKR.
- *Epidemiological*: Fatalities (FARS), key word.
- *Observational Techniques*: conflict studies, traffic flow.
- *Case Study*: accident reconstruction, causal investigation.

From this list, some measures are more likely to contribute to understanding driver performance, behaviour, and system impacts of ITS applications while others are not.

Zaidel (1991) discusses a framework for determining which human factors measures are most appropriate. He emphasizes three types of measures: 1) vehicle guidance and control, 2) allocation of attention between tasks, and 3) higher order processes that govern traffic negotiation such as situation awareness and safety envelope. Zaidel's list of measures (1991, p. 49, Table 6.4.1) is categorized by information source (sensor, driver report, expert observer, and traffic data) and information type (driver state, task processing, and quality of driving). Important measures are: speed, headway, mental workload, driver strategies, eye movements, steering wheel control, traffic records, and expert judgment of quality of driving (QOD). Whether QOD can be reliably judged by experts (driving instructors) is an issue.

A number of higher order variables are described (Zaidel, 1991) and tested (Zaidel, 1992). Traffic negotiation is defined as the "perception and evaluation of a dynamic environment and a knowledge base that includes a model of the traffic system, rules of driving, personnel travel objectives, and expectations of what a reasonable other driver might do" (Zaidel, 1991, p. 11). Overall, how drivers perform with an ITS application *on the road* is stressed as a necessary condition to the determination of safety.

Green (1995b) reviews the development of dependent variables within transportation human factors that have the possibility of determining the safety of ITS devices, in particular navigational devices. Green's (1995b, 1995c) research falls within the scope of a larger body of contract work performed for the FHWA, which is described in Green (1997). A variety of desirable properties of dependent variables are also discussed by Green and used to evaluate those reviewed. Inclusion of a study in the review was based on whether the study used at least a driving-like task.

Recommended performance measures are standard deviation of lane position, speed, and speed variance. Eye movement measures, which can indicate the attentional demands of in-vehicle displays, are suggested with some caveats. Eye movement measurement requires considerable technical and data analysis expertise, although technical developments are easing these requirements. Error rates and response times are indicative of the usability of ITS products, although the relationship between these measures and accidents (as with other performance measures) has not been clearly established. Time to lane crossing (TLC) and time to contact (TTC) may become important as more empirical research with these measures accumulates (e.g., Wikman et al., 1998). Constraints such as time and money can affect the collection of many dependent variables.

In a subsequent report, Green (1995c) describes criteria for a good test, whether government, industry, or independent laboratories should conduct a test, the qualifications of a human factors engineer or specialist (i.e., certification), suggested formats for the presentation of results, the properties of safety limits in other domains, and protocols for conducting tests. Examples for each topic are provided. In essence, factors that affect the choice of independent variables, controlling extraneous variables, and executing a study are addressed. In particular, where a study should be conducted (i.e., context), the choice of independent measures, the selection of participants (i.e., subjects), suggested testing protocols, and data analysis are discussed in detail. Two testing protocols are described in detail. On-the-road testing is suggested when new designs or major redesigns are to be evaluated. Usability tests may be sufficient when minor design changes are implemented in an interface. On-the-road testing is time-consuming (i.e., logistically and analytically) and costly (time, instrumented vehicle, analysis).

Acceptance levels for various measures (specifically, speed SD, lateral SD, frequency and duration of glances, turn error, and percentage of usability errors) are specified at three levels: best case, worst case, and desired/planned. Comparison of collected data to these suggested performance acceptance levels is desired both in terms of confirmation of the acceptance limit and in terms of generating discussion of what is or is not acceptable driving performance.

In discussing the advantages and disadvantages of industry performing evaluation tests, corporations that are in the process of researching and developing a product will likely oppose the release of results from evaluation tests because this release of information may compromise the competitive advantage of an innovative design. Green (1995c) suggests that industry be allowed to carry out testing and evaluation as they already do this for emission testing. Evaluations that are completed at the end of the product design cycle (i.e., product roll-out) will address the government “safety” requirements. However, if a product were found unsafe or marginally safe pending some fix, the costs associated with correction are considerably more than if the product had been evaluated at an early phase of design and fixed at that time.

7.4 Potential Evaluation Measures and Methods

A number of measures and methods are expanded from the lists of Green (1995b) and Zaidel (1991). The approaches and methods outlined in Table 7.1 have the potential to affect the design and development of future ITS applications. The sensitivity of each measure to detect differences where important, real-world differences exist, is important (Zaidel, 1991).

Table 7.1. Available ITS Evaluation Measures and Methods

Method/Measure	**Domain**	**Representative Reference**
• Eye movements	Driving	Wikman et al. (1998)
• Human error	Driving	Treat (1979; 1980)
• Time to lane crossing (TLC)	Driving	Godthelp (1984; 1988) Godthelp et al. (1986)
• Time to contact (TTC)	Driving	Schiff and Detwiler (1979)
• Mental workload	Driving	Verwey and Veltman (1996) Schlegel (1993)
• Quality of driving	Driving	Zaidel (1991; 1992)
• Perception-response time	Driving	Olson and Sivak (1986)
• Behaviour feedback formalism	Driving	Evans (1985; 1991)

Eye movement measures have a long history in driving. Looking at in-vehicle information for prolonged periods (glance duration) or a number of times (glance frequency) has been suggested as a safety proxy (see, e.g., Green, 1995b; Wierwille, 1993; Zaidel, 1991). Where the eyes return after looking at an ITS application is also important. Narrowing of the return glance to only the forward view, and not across other events and information in the traffic environment, may lead to missed events (Antin, 1986). Wikman et al. (1998) found that novice drivers sample in-vehicle controls and information using longer glances (> 3 s) than more than experienced drivers. The emergence of effective information sampling patterns may be acquired with extensive driving experience. A logical extension of this line of research is whether safe sampling patterns can be shaped so that other important signals are not missed. Recall that older drivers tend to miss events already.

Many variables, such as the use of perception-response time (Lerner, 1994; Olson and Sivak, 1986), have been the basis for a number of highway design standards and accident investigations. Human error is expanded in Section 7.6. Mental workload (MWL) is best used to identify where periods of underload or overload may impinge on the safe operation of a vehicle. The time resolution of MWL is particularly problematic and thus perceptions of workload attributed to specific ITS functions or traffic conditions may reflect a composite perception of multiple events (Verway and Veltman, 1996). If a specific MWL measure can be directly linked to a specific ITS function and performance measures also indicate the function is problematic, redesign is indicated.

Evans (1985) fits 26 safety effects reported in the literature to an equation that relates engineering changes and interactions in the transportation system to actual safety benefits. Two types of engineering changes were considered: those where a safety benefit was expected and those changes made to achieve other goals but also expected to decrease safety. Adequate data about a safety device must be available before system safety impacts can be analyzed. While the safety benefits of ongoing research on interventions for older drivers is anticipated, the actual safety benefits derived from such interventions are not known. The difficulty of predicting the impact of the ubiquitous third brake light is such an example (see, e.g., Farmer, 1996).

Multiple measures may strengthen the inference that particular design features influence driving performance. Multiple measures may also provide equivocal and uninterpretable data. Many studies in ITS tend to adopt a shot-gun approach to collecting dependent variables where many variables are collected and the importance of each is sorted out during the analysis.

If existing measures of driver performance cannot determine the safety of a device, Zaidel (1991) suggest that new measures are needed. Table 7.2 lists a variety of approaches from other domains that may contribute, over time, to the development of safety and usability related measures of driving. The purpose of listing a variety of approaches, other than those traditionally used within transportation human factors, is to suggest alternatives that may benefit the development of safe ITS applications. The domains of human computer interaction and complex systems may lend important insights in the evaluation of ITS displays. The usability of driver interfaces and the prediction of operator error have been applied with some success in those fields for many years. For example, ITS in-vehicle products, in addition to being safe, should be useful and usable (Landauer, 1995; Nielson, 1997). Usability engineering, cognitive walkthroughs, heuristic evaluations, and protocol analysis are introduced in Section 7.5. Verbal reports or protocol analysis is suggested as a means to obtain active insight into how drivers perceive and act while driving and with respect to their own behavior evaluation (Zaidel, 1991). Acceptance of ITS products is dependent on the alignment of a function that an application provides and the goals of the driver (as well as many other economic and market forces). If function and goal are similar, the application is more likely to be accepted, especially if the driver sees a tangible benefit from using the system.

Table 7.2. Potential ITS Evaluation Methods

Method/Measure	**Domain**	**Representative Reference**
• Usability engineering	Human-computer interaction	Nielsen (1993; 1997)
• Heuristic evaluation	Human-computer interaction	Nielsen (1994)
• Cognitive walkthrough	Human-computer interaction	Polson et al. (1992)
• Protocol analysis	Artificial intelligence/HCI	Ericson and Simon (1993)
• Empirical modeling	Human-computer interaction	Card, Moran, and Newell (1986)
• GOMS	Human computer interaction	Kieras (1988)
• Systems analysis	Military systems	Meister (1989)
• Cognitive systems engineering	Complex systems	Rasmussen et al. (1994)
• Human reliability analysis	Nuclear power	Hollnagel, (1993)
• Cognitive task analysis	Ship navigation, aviation	Hutchins (1995a, 1995b)
• Fault mode analysis	Medical accidents	Senders (1994)
• Critical incident technique	Aviation accidents	Flannagan (1954)
• Generic error modeling system	Aviation accidents	Reason (1990; 1995)

Implicitly, certain methods may cost more than others. Usability engineering methods are intended to be used early in the design cycle and cost little. System approaches (Meister, 1989), detailed cognitive task analyses (Hutchins, 1995a, 1995b), or convergent mental workload measures (Verwey and Veltman, 1996) require considerable time and expense to be performed well. The rewards of these methods are paid back, in theory, by the quality of the solutions that are derived. Other methods may be more applicable in certain types of interfaces. For example, reliability analysis may have a closer fit to CAS, whereas usability engineering may have a tighter fit with driver information systems. If an intelligent transportation system is likely to precipitate unsafe behaviours or human errors on the part of the driver, such as when conflicts occur between traffic control devices and in-vehicle display information, then approaches such as ecological interface design (Vicente and Rasmussen, 1992), generic error modeling system (GEMS) (Reason, 1990), or fault mode analysis (Senders, 1994), are suggested.

An underlying continuum of time constraints must also be considered in any approach. At one end of the spectrum of interaction, response is imperative. For example, a collision avoidance system may require that information be presented to drivers so that they have enough time to act on it; for example, in a left-turn near miss. At the other end of the continuum, interaction with an interface, such as in a driver information system, may not require immediate action. Therefore, some methods developed for use where time constraints are less imperative, such as nuclear power and aviation, have distal time horizons and thus may not be applicable.

Driving can be self-paced and/or time-constrained. Some driving tasks are imperative or dictated by the context of the traffic environment at a given moment, while others tasks can be scheduled at the leisure of the driver. A strong motivation to reach a destination may limit the flexibility of self-pacing (Gibson and Crooks, 1938). In other words, the degrees of freedom to act may be lost as the result of internal and external constraints.

7.5 Usability Methods

Usability engineering (Nielsen, 1993, 1994, 1997) is based on the concept of user-centered design (UCD). User interfaces can be created to assist users in completing their tasks with minimal stress and maximal efficiency. The UCD principle requires that in all phases of iterative development, user characteristics and needs be kept in mind. The end users (i.e., drivers) are brought into the design process early and often as the product develops. As has been outlined in previous sections, those who are less able users (e.g., older drivers) should be considered integral to product design and testing. This includes providing information on what is needed from the product as well as testing it to determine whether it serves desired functions. It is practical and economically sound that most of the major problems that the user is going to face with the interface be rectified before it enters the market place.

While this collection of methods is widely used in the human-computer interaction (HCI) community, these techniques are not used nearly as frequently in the ITS human factors community. There are a few exceptions. Hancock et al. (see Hancock and Caird, 1992; Hancock and Parasuramen, 1992; Hancock, Dewey, and Parasuramen, 1994; Hancock, Parasuramen, and Byrne, 1995) have advocated a human-centered approach that emphasizes human requirements as opposed to technology requirements. This is a caveat of usability engineering. Parkes (1991) discusses a number of subjective and performance measures similar to those described by Green (1995b) and Zaidel (1991) under the title of usability. Green (1995c) suggests that usability tests be performed at drivers licensure offices where a representative sample of drivers may be obtained, as opposed to using a convenient group of engineers or college students.

Different techniques are used to assess interface usability as an interface is developed. These methods may include focus groups, surveys, cognitive walkthroughs, heuristic evaluations, usability testing, and ethnographic studies (e.g., contextual inquiry). At the start of product development, focus groups and surveys can be used to assess user needs for the product. Focus groups with representative users are helpful in evaluating the preliminary concepts of the product. These issues can be explored in depth with relatively small groups which provide critical information on what the users want to be able to do with the product. Green (1995a, p. 1007) provides a cautionary note however: "[f]ocus group participants cannot provide useful input concerning driver interaction[s] that are beyond their experience." Surveys of a larger group of potential users can be used to find user characteristics and preferences. General preferences for particular ITS technologies can be assessed, but should be weighed in light of experience with a product and driving performance measures that might be obtained later in the development cycle.

After focus groups and surveys are conducted to assess potential acceptance, a paper prototype design can be developed and evaluated (see, e.g., Green, 1995c). For example, cognitive walkthroughs may be used to explore how a driver might fare with a product. How a prospective driver performs mock tasks with the prototype is questioned, focusing on cognitive theory. Designers go through the product functions (e.g., moving from one level of the interface to the next) keeping in mind user goals, knowledge, and expectations.

Heuristic evaluations are performed by usability specialists or human factors professionals. These experts, using a set of usability heuristics or principles (see Nielsen, 1993, 1994, 1997), assess the usability of the product prototype, find problems, and bring forth critical design issues. Usability experts are not usually domain experts (i.e., experts in the field which the product is being designed). Heuristic evaluations reveal some of the major design flaws that restrict usability, and these flaws are resolved by the design team by making modifications to the product. Approximately 80 percent of the usability problems in a product can be detected with seven test evaluators. Beyond seven, the identification of additional usability problems requires more and more evaluators; that is, the number of problems identified begins to asymptote.

In a usability test that may follow a heuristic evaluation, a representative sample of users attempt to complete pre-defined tasks with the product/ interface. Usability tests, conducted during early phases of development, can be extremely useful as they are inexpensive and quick to set up. They are usually the first contact that both the designers and the users have with product prototype together and can result in critical user feedback (i.e., criticisms and solutions). Participants are given a number of scenarios to accomplish to determine the difficulties that they may have using certain functions. Easier scenarios are given first, followed by more difficult ones. Thus, the user is given the opportunity to gain confidence with interacting with the product, before more problematic design functions are tested. Minimal guidance is provided to the user while interacting with the interface. Participants may be encouraged to "think aloud" while interacting with products (see, e.g., Ericson and Simon, 1993). Thinking aloud entails verbalizing actions, thoughts, and confusions while doing something. Transcriptions or video-audio records of thinking aloud can provide anecdotal evidence to developers that a particular function or feature is problematic and requires redesign. Thinking aloud data come with a variety of interpretive caveats that are largely ignored by the usability community. Consultation with Ericson and Simon's book (1993) is recommended. If verbal protocols are used for analysis purposes, the process is exceptionally time-consuming.

If many users find a scenario difficult or impossible to accomplish, this evidence suggests that particular interface features should be redesigned. A collection of verbal and performance data is analyzed and prioritized such that more important features are corrected by a design team in order of criticality. An iterative process of analysis, test, fix, and so forth is essential to the timely delivery of an usable interface. The primary advantage of conducting usability tests over full experimental designs is that fewer participants are needed. Several disadvantages of usability testing are also known. The attribution that a certain function is “usable” based on five to seven participants is not always clear. For example, three of six users could do function x, whereas three could not. The question remains whether function x needs to be fixed. For some design functions, such as icon comprehension or application feature ease of use, a higher N may be required such that a more conclusive result can be determined. Green (1995c) suggests 100.

Importance of the function and verbal protocol may inform whether to highlight the difficulties experienced by participants. Arguments that certain functions are difficult to use tend to be based on the ordinal frequencies obtained from a limited number of participants. The fact that a scenario was difficult to perform does not itself suggest which design improvement is to be made (i.e., in the interface or to training). Usability methods do not prescribe a comparative group and thus all obtained data are purely descriptive. The descriptive data are used to argue that particular changes are necessary in product. The usability specialist is left the task of subjectively prioritizing, often with considerable disagreement from engineers and programmers, the necessary changes to be made for that particular design stage. Many of the steps outlined so far are repeated as resources and priorities make it possible before the delivery of a product to market.

Once the product has entered the marketplace, then field (ethnographic) studies may provide information on how the product is used and performs in real driving settings. This information may not necessarily result in drastic changes in the product's design, but can provide suggestions on future releases of the product that may address new uses of the product not originally envisaged by designers. For example, mobile phones and navigation systems have proliferated to the point where ethnographic studies may identify new market niches.

Applications that have been usability tested with appropriate changes integrated into product redesigns, have other barriers to overcome before product safety can be determined. Usability engineering methods afford a cost effective means to evaluate ITS applications in formative stages. It is probably true that if an ITS application has been usability tested and appropriately modified, it is less likely to impair driving performance. However, the determination of the performance of drivers with a system, so that an indication of relative safety can be acquired, should be measured using alternative methods such as driving simulation and on-road testing (Green, 1995c; Zaidel, 1991).

7.6 Human Error Methods

At several levels of analysis in the transportation system, the consequences of different forms of driver error that may result from the introduction of new ITS technologies must be considered (Brown, 1990; Reason, 1990; 1995). Driver error has been the focus of several special issues of the journal *Ergonomics* (Vol. 31, No. 4; and Vol. 33, Nos. 10/11). Some of the issues raised in these articles apply to ITS applications. In particular, the kinds of errors that drivers are likely to commit in the presence of new technology should be anticipated. Different ITS applications are likely to precipitate different kinds of errors. Certain types of errors that ITS applications may elicit may be identified through the analysis of prior accident investigation studies.

Treat et al. (1979) and Treat (1980) provide a highly detailed analysis of driving accidents that reveals primary reasons why accidents occur. The tri-level approach taken by Treat et al. (1979) examined 13,569 police-reported accidents in Monroe County, Indiana (Level A). From these, 2,258 on-site accident investigations were conducted using causal investigation techniques immediately after an accident occurred (Level B). More complex investigative procedures were applied to 420 accidents by a multi-disciplinary team (Level C). Various factors were classified as "definite" (95% confidence) or "probable" (80% confidence) causes, where a causal factor indicates that the accident would not have occurred had the factor not been present.

A primary conclusion was that human errors (70.7%) contributed significantly more to traffic accidents than did environmental (12.4%) and vehicle (4.5%) factors. A definitive causal classification into driver, environment, and vehicle could not be made in 20% of cases. The in-depth analyses revealed that human factors contributed from 70.7 to 92.6 percent (definite - probable) of accidents. Results of the on-site analyses were only slightly lower than these figures (64.3–90.3%). With the exception of false assumption and improper manoeuvre, all in-depth (Level C) percentages are 3 to 6 percent higher than on-site (Level B) percentages.

While it is evident that accident causes typically do not occur in isolation (i.e., multiple causes contribute to accidents), Treat et al. (1979) found that 57.1 percent of the accidents studied resulted from exclusively "human only" factors and 26.4% resulted when human and environmental causes were contributory. The most commonly occurring human factors were recognition and decision errors. A further breakdown of these errors is shown in Table 7.3. It shows ten categories and associated percentages for "specific human-direct-causes" from the in-depth analysis (Level B). Appendix A (Treat, 1980) lists the specific criteria used by the investigators to categorize each accident. Of particular interest, Treat et al. (1979) found drivers 65 years of age and older to be over-involved in "improper lookout" accidents. An improper lookout error is a combination of either "failed to look" or "looked but failed to see" (Treat, 1980, p. 8).

Table 7.3. Human Error Causal Factors of Traffic Accidents Derived from In-Depth Investigations (Level B) (Adapted from Treat, 1980, Figure 4, p. 9).

	Definite	Definite or Probable
Improper Lookout	17.6	23.1
Excessive Speed	7.9	16.9
Inattention	**9.8**	**15.0**
Improper Evasive Action	4.8	13.3
Internal Distraction	**5.7**	**9.0**
Improper Driving Technique	6.0	9.0
Inadequately Defensive Driving Technique	2.4	8.8
False Assumption	**4.5**	**8.3**
Improper Manoeuvre	5.0	6.2
Overcompensation	3.3	6.0

Inattention, internal distraction, and false assumption are highlighted in Table 7.3 because it is these causal categories that are most likely to capture errors associated with using in-vehicle ITS equipment. Inattention is defined as "a non-compelled diversion of attention from the driving task", whereas an internal distraction was defined as a "diversion of attention from the driving task that is compelled by an activity or event inside the vehicle" (Treat, 1980, p. 9). A false assumption is defined as making a decision based on a true condition of another driver or traffic environment that is, in fact, false (Treat, 1980, p. 22). Assuming that another driver will behave in a particular way when they do not, such as stopping for a yellow light, is an example. Assuming that another driver has a VES when they do not, is another.

In an interesting side note, Treat (1980) mentions that during the data collection, from 1972 to 1975, there was an increase in accidents caused, in part, by 8-track and tape players which represent an internal distraction. Conceivably, other categories in Table 7.3 may be implicated depending on the demands of the device and the adaptive responses of the driver to it. For example, excessive speed, if found in an evaluation, may be the product of behaviour compensation of a driver to an ITS application. These categories may reflect the kinds of errors that may result from interaction with an ITS product. If an evaluation discovers these errors, steps should be taken to identify the origin of the error and remove it. Positive driver adaptations, such as increased headway, should not be eliminated at the same time (see, e.g., Senders and Moray, 1991).

Classification of vehicle accidents into inattention, internal distraction, and false assumption with an ITS device as the contributor is not possible without a means to link the category to the accident data. The forms that are used by the police to classify traffic accidents do not include the category of ITS device. For example, mobile phone use prior to an accident is just being considered for inclusion on some accident forms (see, e.g., NHTSA, 1997). Without data to establish the incidence of ITS-related accidents, a large-scale investigation similar to Treat's (1980) may be able to determine the frequency of these occurrences, although this study would be costly.

Another way to use accident databases is to query them with plausible questions. Wierwille and Tijerena (1996) employed a key word search to North Carolina accident database for 1989 and one third of 1992 (also see NHTSA, 1997). A set of object words was used to search accident narratives for instances where attention was drawn inside the vehicle, outside or in an unspecified manner. To be included in the classification scheme, two criteria were used. First, vision was directed in some way by the object from the forward view and second, visual allocation of attention was the primary cause of the accident. The 1992 frequency data are based on an extrapolation (x3) of the occurrences. Overall, more cellular phone and fewer CB radio accidents occurred in 1992 than 1989, which is in accord with expected usage patterns. Radio, two-way radio (CB), HVAC, instrument, seat-belt, mirrors, reading in the vehicle, visual occlusion, and interaction with a person or animal formed the primary categories of attention errors. Those objects that required immediate attention, such as waving away a wasp or getting a guinea pig from underneath the accelerator, were particularly distracting. If a database of Canadian accident narratives could be searched for visual attention accident contributors, HVAC is likely to be higher here than in warmer climates. Using the same analysis methods but stratifying by age, is likely to identify whether younger and older drivers differ in the kinds of objects that distract them from driving. The identification of instances where visual attention failures contribute to accidents adds insight into the safety of in-vehicle devices. Reliance on accident reports has a number of attendant difficulties, including record accuracy, completeness, category interpretation, investigator training, and so forth.

Prevention of errors through careful design and evaluation is a fundamental design principle (see, e.g., Nielsen, 1993). While this is the ideal, in practice it is difficult to achieve for a number of reasons. The occurrence of driver errors may not be detected. The time scale of many evaluation methods is quite short and the focus of measures taken is not necessarily directed at the infrequent occurrence of errors (see, e.g., Chapanis, 1988). The acquisition of skill in using a new piece of technology while driving—especially for older drivers (Holland and Rabbitt, 1992)—requires prolonged periods of practice and specific feedback (also see Section 4.6). The length of training time necessary to produce adequate levels of performance is experimentally expensive. The kinds of error forms that may emerge after habitual use of a device in the absence of adequate training or with a poor design is likely to occur infrequently in hundreds, if not thousands of trials (see, e.g., Schmidt, 1989; Wierwille, 1991). Errors may also not be captured in the evaluation process because expectations placed on participants tend to produce optimal performance under conditions of heightened arousal. The act of observation may interfere with the naturalistic occurrence of potential error behaviour. Finally, those who may stand to gain by a favourable evaluation of a certain ITS application may overlook errors as a dependent measure for obvious reasons.

7.7 A Guideline and Evaluation Framework

Integration of guideline and evaluation methods is one objective of this report. Figure 7.2 provides an overview of the contribution of human factors design guidelines (Section 6) and evaluation methods (Section 7) to the guideline and evaluation methods framework. A number of conclusions are drawn based on the framework (Section 8). Consultation with a collection of guidelines is likely to yield few constraints on which to design and develop an ITS application. However, in the absence of knowledge about specific ITS application design and performance with it, new knowledge must be generated.

An evaluation framework that loosely pairs an evaluation approach with the stage of development of an ITS technology is shown in Figure 7.3. The left-most column illustrates the general relationships between design products, evaluation processes, experimental type, and cost. Design products tend to begin as a concept and various prototypes are developed. The viability of a prototype over others is determined iteratively or otherwise and developed into a product[2]. Providing there is some means to determine and compare relative safety (e.g., acceptance limits) (Green, 1995c), the necessity of determining acceptable performance level increases prior to product roll-out. As prototypes and products are developed, a range of evaluation methods are available to test applications. Focus groups and usability engineering represent a set of possible techniques that could be applied. The remainder of methods listed and experimental studies through accident databases, do not necessarily represent a continuum.

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[2] The design description is overly simplified here. The design process is exceedingly complex and is considered in depth by others (e.g., Norman, 1988; Simon, 1981).

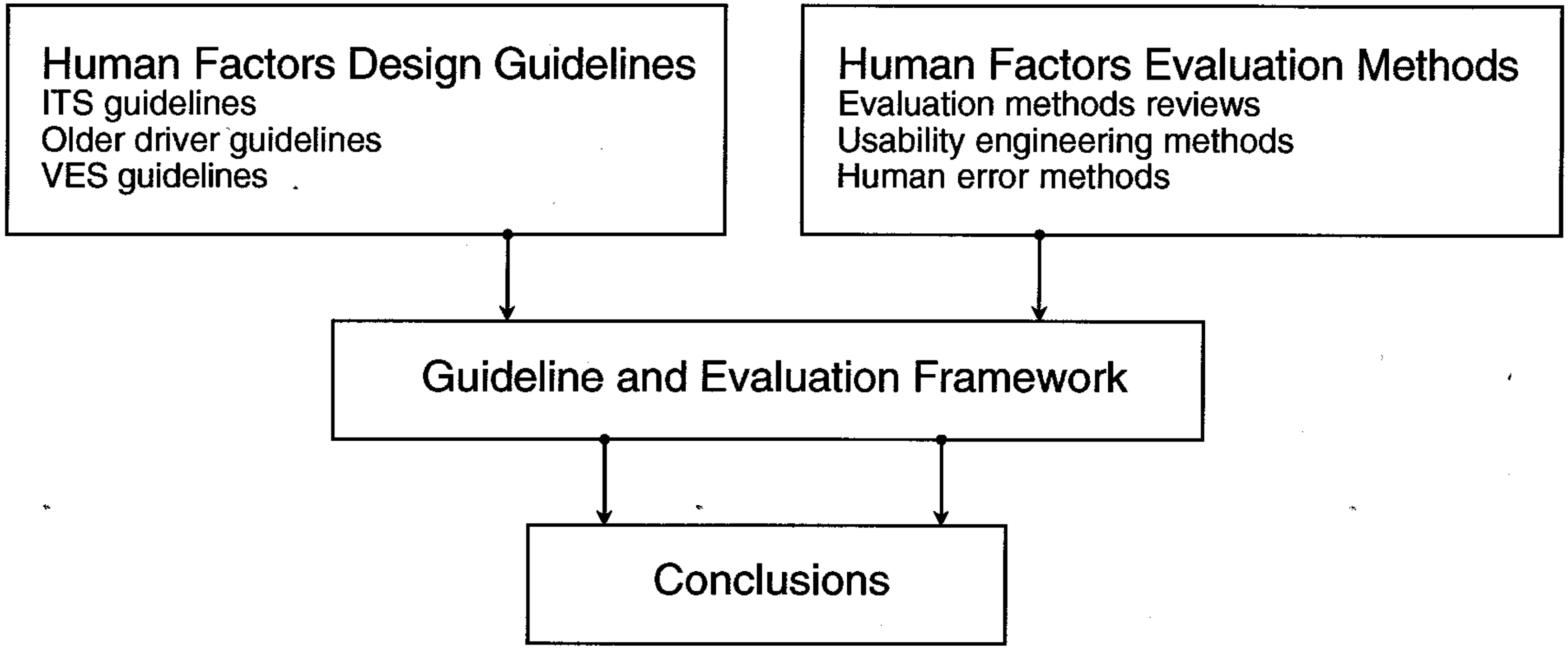

Figure 7.2. Overview of guideline and method contributions to the guideline and evaluation framework.

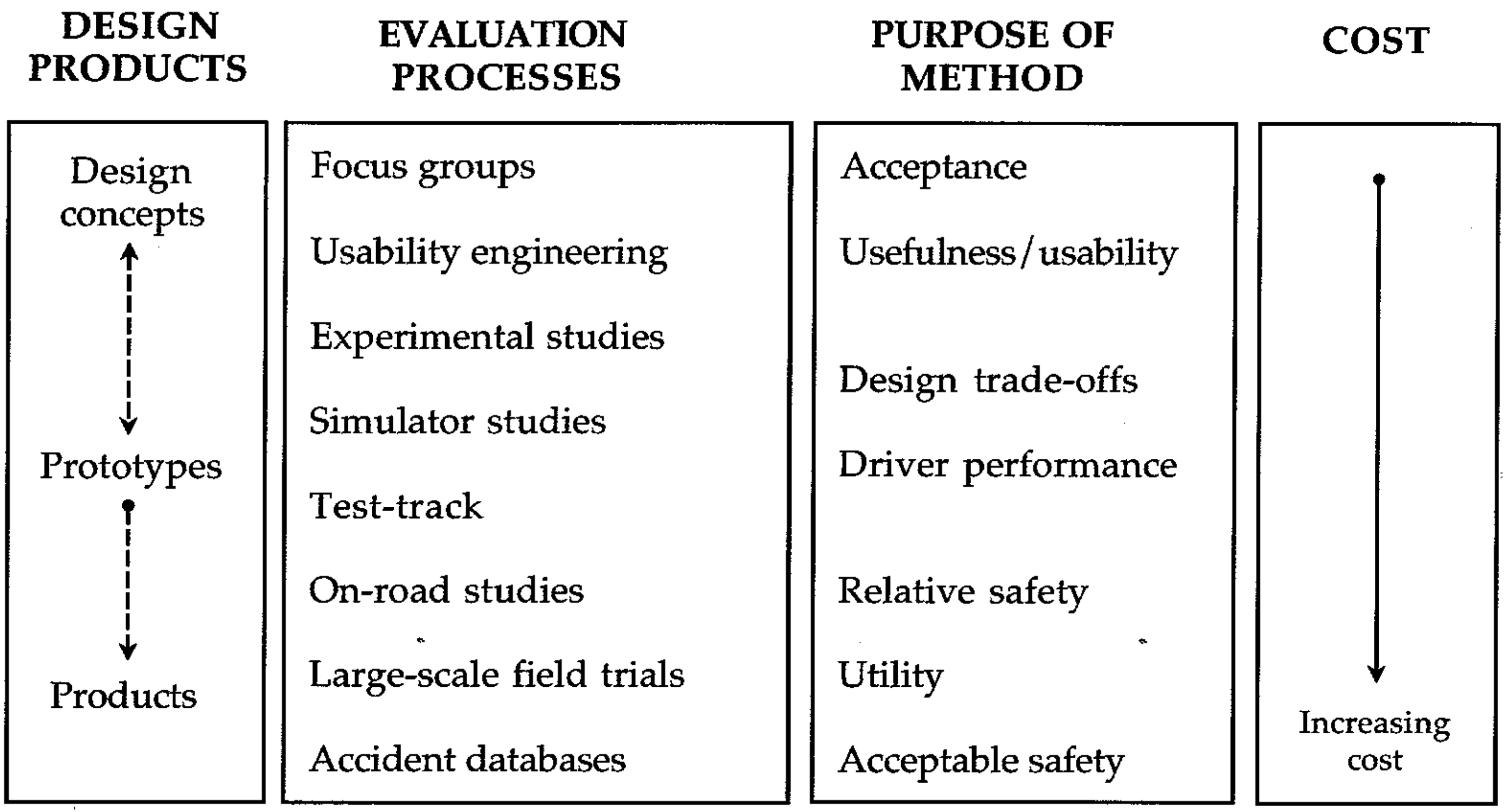

Figure 7.3. Nominal relationships between design products, evaluation processes, purpose of method, and cost. See text for details.

"[Driving simulation] is not sufficiently realistic for assessing safety effects" (Zaidel, 1991, p. 30). In particular, simulation of adequate roadway demands (i.e., traffic volume, expected and unexpected behaviour of other drivers, signs, etc.) is problematic. Numerous researchers have noted that driving simulation provides an intermediary method of evaluation without endangering the participants. Driving simulation validation (i.e., the explicit comparisons between dependent variables in the simulator and the real world), has had more researchers note its importance than substantive research (TRB, 1992; 1995). The danger is that if a dependent variable bears little similarity to real-world driving behaviour then the justification for an expensive driving simulator is suspect (Caird, 1996). How a luminance and resolution impoverished cartoon image responds with lags to steering, brake, and accelerator inputs, strains the credulity of some researchers. The generality of such system measures, like criticisms of laboratory experiments, should be open to inspection and debate.

Experimental design, like design, must satisfy a number of goals simultaneously. The appropriate pairing of an ITS application and evaluation process is based on experience with a particular method, belief in the efficacy of the method, cost, the stage the design product is at, the selection of pertinent independent and dependent variables, the aimed for generalizability of the study, and so forth (see, e.g., Cambell et al., 1997; Green, 1995b, 1995c; Meister, 1989; Smiley, 1996). Experimental, driving simulation, and test track methods are useful to compare whether two devices are better or worse than one another (Zaidel, 1991). On-the-road studies help to develop baseline performance data to which comparisons can be made (Green, 1995c).

Many ITS applications may be categorized as intended to achieve other goals such as improved navigational efficiency, but nonetheless will have an impact on driver safety. Determining the interaction effects of ITS applications requires what amounts to a clinical trial for that application. A sample of drivers with an application must be compared to another sample without the device (i.e., a control group) where demographic, roadway, and environmental parameters are held approximately equal between the two groups. Cost and logistics will require the coordinated efforts of govenments and corporations (see, e.g., Fleischman and Dingus, 1998).

Positive and negative impacts of an ITS application can influence both the driver and the collective of drivers directly and indirectly. Individual impacts of ITS applications have been foreseen and addressed in ongoing traffic safety research. However, outside of large-scale evaluations such as Fleischman and Dingus's (1998) TravTek, collective impacts of ITS applications on costs and benefits have not been measured. For example, do navigation devices actually save time and distance traveled (i.e., utility)? The question is whether individual and collective impacts can be determined prior to large-scale evaluations. Within large-scale field trials, the occurrence of accidents is likely to be the exception unless considerable exposure is accumulated within the evaluation time window. Accidents are rare events in a driver's lifetime (Evans, 1991) and in large-scale evaluations. Accident databases which reliably capture the precursors of accidents establish the "bottom line" or acceptable level of safety of a system.

With more product development and evaluation, costs increase (see Figure 7.3). Parkes (1997) states that ISO, TC22, SC12, WG8's has a priority to determine methods that can assess the relative *safety cost* of various ITS technologies. Safety cost can be interpreted as either the value of the processes necessary to determine that a product is "safe" or the cost of a particular ITS technology on the acceptable level of safety of the transportation system. The costs of processes necessary to make a system safe are quantifiable, whereas the transportation system safety costs accrue over a long period of time and the true cost is very difficult to determine.

When an evaluation test is performed, the process, participants, and materials used must be adequately described such that another evaluation team could repeat the study on the basis of the description. Specifically, the selection of participants, the description of the test environment (whether simulated, test track, or roadway), the selection and measurement of independent variables, and exact steps taken to carry out the study need to be adequately described (see, e.g., Herzog, 1997). When space is limited in a technical report or conference proceedings paper, methods and procedures tend to be the first area that researchers reduce the length of the paper. Reviewers of conference proceedings should recommend to authors that methods sections should meet the criteria that if someone reads it, they should be able to replicate the study. Accurate specification of the traffic environment (traffic volume and interaction with others) tends to be problematic.

Each study adds information to the understanding of the acceptance, usability, usefulness, performance, design trade-offs, utility, and safety of a device. A single human factors study with a given ITS device is insufficient to establish the outcome of all these dimensions of evaluation. Developers like to talk about what they have been doing even if their research is not optimal. The processes that they choose to engage in must, nevertheless, tell them something about the system they are trying to design. What knowledge is gained by developers, despite potential limitations, should be shared in some form with others. Thus, an incremental, iterative development and test approach is necessary.

7.8 The Framework Applied to VES

The VES studies, which were discussed in detail in Section 5, are examined in light of the evaluation processes and purposes outlined in Figure 7.3. Studies on IVES, in the open literature, are simulator and on-road based. Implicitly, focus group and usability studies were conducted by companies developing IVES prior to these tests. Often, companies don't do usability testing, however. Guidelines may or may not have been used to develop the evaluated systems. Lessons learned from these design decisions are likely to reside in the heads of the design team members.

Table 7.4 An Overview of IVES Methods and Measures.

Study	**Study Context**	**Dependent Variables**	**Participants, Methods Notes**
Nilsson and Alm (1996)	Brake to an unexpected event in the VTI driving simulator with an IVES.	Perception response time, speed, lateral lane position, SD of lane position, NASA-TLX.	N= 24 (12 Men, 12 Women), aged 23 to 46 (M = 33.5, SD = 7.5).
Ward et al. (1996)	Respond to scenarios imbedded in a video-simulated IVES.	Correct/incorrect gap acceptances, estimated time-to-contact.	N= 16 (8 male, 8 female), aged 20 to 70 (M= 41), 8 younger (<25), 8 older (55+), missing data.
Bossi et al. (1997)	Detection of Landolt C's at 10°, 15°, 20°, and 25° off foveal centre while tracking a lead vehicle in an IVES simulation.	Correct and incorrect identifications, reaction time, incidental verbal responses, cumulative tracking time.	N = 13 (6 M, 7 F) aged 24 to 39 (M = 31.5), unusual tracking analysis.
Ståhl et al. (1994)	1.1 km airfield test track.	Verbal response to object recognition, distance to object, subjective perception of ease of use	N = 15 (4 women, 11 men), aged 65-80.

Ward et al. (1994).	Nighttime 1 km rural driving route with a bend.	Speed variability, NASA-TLX-R, Response Time.	N = 5 (3 male, 2 women) median age = 26, missing data.

The potential advantage of an IVES is in the detection and response to human and animal hazards. Nilsson and Alm (1996) use the dependent variables recommended by Green (1995b). Dependent variables from other studies speak less directly to the relative safety of driver performance. Ward et al. (1996) and Ståhl et al. (1994) include an older driver sample. Unfortunately, a precise description of the characteristics of these participants is not reported. None of the studies in Table 7.4 have been published in a peer reviewed journal. Other limitations are self-evident and discussed in Section 5.

Table 7.5 An Overview of UVES Methods and Measures.

Study	**Study Context**	**Dependent Variables**	**Methods Notes**
Ståhl et al. (1994)	Test track with UV sensitive materials.	Perceived visibility, perceived glare, visibility distance	N= 31 (27 male, 4 female), former Volvo employees, divided between age groups of 65-69, 70-74, 75+ compared to 24 younger Volvo employees
Fast (1994)	Swedish public roads and test track.	Questionnaire of perceived visibility	N= 40
Mahach et al. (1997)	On the road four lane divided highway between 7 and 11 p.m.	Subjective ratings of visibility, visibility distance	N = 36, (13 younger males, 8 younger females, 7 older males, 8 older females), young = 25 - 45. older = 65+

Turner et al. (1997)	Test track.	Detection distance, recognition distance, subjective ratings	N = 28 (16 female, 12 male), 8 aged 16 to 25, 14 age 26 to 59, 6 aged 60+, older data not reported.

Studies conducted on UVES to date have been on test tracks and on the road. The selection of dependent variables is specific to those that indicate increased visibility. Lane variability, speed, speed variance, workload, and eye movements have not been used and may provide useful data. Increased speed is a possible outcome behaviour of increased visibility. Lane variability may indicate that with greater visibility, vehicle control is improved. Seeing further ahead may also reduce workload. Highlighting particular properties of the traffic environment with fluorescent material may attract the attention of drivers to the exclusion of other importation information sources. How the enhanced properties of the environment affect eye movement patterns is an important question. A substantive theoretical treatment of what should be more or less visible in the traffic environment could be used to guide the selection of measures and what properties to enhance.

7.9 Evaluation Decision Checklist

The purpose of a decision checklist is to generate discussion within research groups or development teams about the relative importance of selecting individual, vehicle, traffic, environment, and paradigmatic possibilities. Green (1995c) explains many of these decisions in greater detail. Appropriate research designs are likely to require self-pacing, varying real-world driving, sufficient practice with the device of interest, a representative sample of drivers, and consideration of individualized strategies that drivers may adopt while using that device.

Participants

- What are the sample characteristics of the individuals in the study? (male, female, younger, older 65 to 74 or 75+)
- Is there likely to be age differences on variable(s) of interest?
- Is the product market segment for the product aimed at the entire driving population or a particular subset? (e.g., younger or older)

Environment

- What is the appropriate paradigmatic context to conduct a study? (focus group, usability test, laboratory, driving simulator, test track, on-the-road, field study)
- At what development stage is the product that is being evaluated (see Figure 7.3)? (initial design, prototype, working prototype, product)
- When is the test performed (i.e., time of day)? (day, night, dusk)
- What is the weather? (rain, snow, sleet, hail, ice, fog)

Roadway

- Where is the driving route that is being considered? (urban, rural, suburban) (prescribed route, test track, simulated)
- What traffic events are to be encountered by drivers? (expected and unexpected behaviour of other drivers, emergencies, prolonged waiting in traffic, etc.)
- Are these events or scenarios representative of actual driving? (e.g., overtaking, merging, waiting in congestion, etc.)
- What is the appropriate level of traffic density? (suburban, rural, urban, freeway; low, medium, high)
- What is the road geometry? (lane width, shoulder width, sight distances, curviness, types of intersections)
- What signs and signalization should be included?
- What is the appropriateness of the response of the driver to the demands of the roadway context, that is, lane tracking or speed variance connected to what events?

Vehicle

- What vehicle will your participants be driving? (own car, an instrumented vehicle, simulation mock-up)
- Has the driving simulator been validated on the dependent variable(s) of importance?

- How accurate are the vehicle dynamics of the driving simulator? (handling, acceleration, and deceleration)?

- What is the system lag and image resolution and do these and other simulation variables address the level of fidelity needed to produce expected generalizability?

Experimental Design

- Is a baseline group needed to compare the frequency of accidents and/or injuries or test performance with a system to those without?

- How much practice does a participant need to have with a device? (15 minutes, one hour, one day, one week, one month)

- Should participants interact with a device in a self-paced fashion or are task interactions imposed by the experimenter?

- Will drivers in the real world be interacting with multiple devices? (i.e., multiple ITS devices and/or ITS applications and older technologies such as HVAC)

- Are the tasks to be performed representative of expected usage patterns?

- How are they driving? (conservatively, normally, dangerously)

- Are protocols in place to reinforce "normal" driving?

- Are motivational difficulties expected with a device? (fatigue, stress)

- Are drivers likely to be impaired when using an application? (drugs, alcohol)

Analysis

- Is there flexibility integrated into the analysis so that strategies that vary across participants can be identified and treated separately? (e.g., speed-accuracy trade-offs, etc.)?

- Is a set of hypotheses expressed in terms of independent and dependent variables and not unoperationalized variables? (e.g., safety, workload)

- What is the accuracy and practical accuracy of the data?

- Are flags set in the data file(s) to mark important events so that data reduction is simplified?

- Will the study, once completed, inform other designers how to design a better ITS application?

7.10 References

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8.0 CONCLUSIONS

Technology has overwhelmed public policy (Walter Wriston, 1997).

Society tends to look to technology for solutions. Issues that arise from an aging demographic shift will require solutions and some will be new technologies. Older drivers may be the beneficiaries of well-designed ITS products. Driving performance losses that accompany aging may be ameliorated by systems that serve to compensate for these losses and extend existing human capabilities. A danger exists that older drivers, if not considered in the development of ITS products, may experience more difficulties than before.

Currently, the impact of ITS technology on driver safety and mobility, given available empirical evidence, is not well understood nor easily predicted. For example, introduction of new technologies is likely to produce unexpected interaction effects such as conflicts in expectancies between those individuals with such systems and those without. Conflicts can also occur between in-vehicle information and traffic environment information.

The development of ITS applications is advancing faster then transportation ergonomics can provide empirical results and theoretical insight (Noy, 1997). Basic empirical knowledge of driver behaviour and compensatory strategies is needed (Green, 1995). Convergent and replicated performance and preference data on the spectrum of ITS in-vehicle products that are being developed is also needed. Once an ITS product enters the transportation system, the determination of an acceptable level of safety[3] is needed (see, e.g. Evans, 1985). Expert estimation of the likelihood that drivers will fail to detect hazards while using an ITS device is also needed (e.g., human reliability engineering or HRA). Assumptions about hazard exposure and interaction frequency should be made explicit.

The emphasis of ITS development programs has been on delivering certain categories of information with minimal regard as to the fit of information into the goal-directed behaviours of drivers. The interpretation of how much information and how it should be presented leaves considerable latitude, despite the development of extensive guideline directories. Designers and engineers who produce ITS applications may still overwhelm the older driver, because the designs that are needed are not available from a guideline checklist. What and why information should appear have not been substantively addressed. It seems that certain information is given to drivers because the technology is available, not necessarily because drivers need it.

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[3] Safety is defined as measurable increases or decreases in the frequency and severity of accidents over levels that existed prior to the introduction of an ITS technology.

A number of issues are clearly important to the successful delivery of ITS applications for older drivers. Issues of mobility, age-related declines in ability, behavioural compensation, guidelines and evaluation methods, and older driver interventions are considered in greater detail.

Mobility. With the projected increases in older drivers on the road—especially women—(Cerelli, 1989; 1994; Transportation Research Board, 1988), many more older drivers in Canada will be dependent on their automobile to shop for food, visit the doctor, and socialize with friends. Between 1983 and 1990, an increased reliance on driving over other forms of transportation was found in both rural and urban areas (U.S. FHWA National Personnel Transportation survey, cited in Eberhard, 1996). Lifelong habitual patterns of automobile use are not likely to easily give way to the use of public transit or other alternatives. In rural settings, public transit is not feasible because lack of demand, logistics, and expense preclude it. Larger Canadian cities tend to be designed such that access to essential needs (i.e., survival, medical, and social) can only be met by driving. Driving tends to be preferred for a variety of reasons. These include the ease of getting into a car, being able to go somewhere at any time, and being able to run a number of errands consecutively. Restrictions to mobility will impair the lifestyles of the elderly. For the overwhelming majority of elderly, the maintenance of independent and meaningful lifestyles will require a wide array of policy, service, and infrastructure solutions. The ability to drive in the face of age-related declines is fundamental to lifestyle maintenance. Finally, what may increase the mobility of the majority of transportation users may impinge on maintaining the mobility of older drivers. The mobility effects of an ITS technology on a population of drivers is not uniform. While some may enjoy benefits of traveling to their destinations faster, others may find that the speed and complexity of the driving inhibits their desire to travel.

Age-Related Declines in Ability. A variety of ITS in-vehicle applications will affect older driver performance. Contrast legibility, divided attention, working memory, and speed-accuracy reductions as age increases are fundamental driver limitations. Each of these limitations is more likely to affect driving performance when the complexity of the traffic environment is high, such as at intersections, in high-traffic volume, and on unfamiliar routes. An in-vehicle display must be seen across a wide range of lighting conditions and, more importantly, across age-related changes in the visual system.

Working memory limitations are more likely to pose a problem when multiple tasks are being executed. Working memory limitations are evident when tasks require remembering critical information while performing another task. Driving can require memory and control tasks to be performed concurrently. Driver navigation and information systems, depending on design, may cause older drivers to forget something. They will have to look more than once at a display to obtain essential information. Excessive division of attention, the need for quick responses to warnings, and long auditory or visual messages are likely to affect the performance capabilities of older drivers.

Division of attention can occur where multiple streams of traffic coincide or when multiple skill repertoires are needed at the same time such as when accelerating into an intermittent speed stream of traffic. Many older drivers trade-off varying degrees of response speed for accuracy. Choosing to respond more slowly and being absolutely sure about certain manoeuvres before deciding to proceed, are manifestations of overall reductions in processing and execution speed. Interaction with in-vehicle technology that requires fast responses or directs attention from the roadway to an interface, is incompatible with declines associated with aging (Caird and Chugh, 1997; Ranney and Simmons, 1993). ITS applications should accommodate the legibility, working memory, attention, and response limitations of older drivers.

Behavioural Compensation. Behavioural adaptation strategies, whether conscious or not, play an important but poorly understood role in buffering age-related declines. Various strategies are used by older drivers to: increase the window of response time (e.g., by decreasing speed); avoid certain traffic situations (e.g., left turns); and constrain driving when some environmental conditions exist (e.g., nighttime and snow). Making older drivers aware of age-related declines in abilities logically precedes adopting effective compensatory behaviours (Holland and Rabbitt, 1992).

ITS products need to complement older driver compensation strategies. Many researchers who advocate the potential of ITS technology for age-related declines in capabilities such as vision assume that the fit between driver and technology is straightforward. The solution to visual decline is somewhat more complex. For example, if older drivers do not drive at night then VES will help them to do so. In latitudes where there is limited daylight in winter, VES seems like a reasonable means to expand the mobility of drivers. VES should be deemed relatively safe and acceptable to older drivers. Specifically, VES should not precipitate accidents and should fulfill a need that is valuable to drivers.

Guidelines and Evaluation Methods. At many points within the development cycle, human factors guidelines and evaluation methods are critical. The utility of these knowledge sources and evaluation processes is routinely debated in the human factors community. For example, the validity and efficacy of many dependent measures in a variety of traffic contexts is less than certain. Some seem to provide reliable information about drivers' ability to control their vehicles (e.g., standard deviation of lane position and time-to-lane crossing), while others do not (e.g., secondary workload measures).

Human factors design guidelines allow designers and engineers to bootstrap their expertise to existing knowledge when approaching new designs. Guidelines can also serve as a checklist to determine whether a prototype has met accepted design and evaluation practices. Catalogs of guidelines can suffer from the inadequate specification of when, where, and how to apply a guideline. Case examples that have served to guide previous design decisions may be helpful. References to the original empirical research upon which a guideline is based should be included in these guideline collections so that the generality, validity, and reliability of a guideline can be checked.

Many evaluations to date (see, e.g., EDDIT, Nicole and Stapleton, 1995) have emphasized older driver mobility as the important dimension of evaluation. Older drivers are typically asked whether a particular device, in their opinion, would increase the likelihood that they would drive more in particular situations with the device after some experience with it. Vision enhancement systems and systems that increased the perception of safety and security, such as AVL, were perceived by older drivers as having the potential to increase mobility. Asking drivers their preference for and impression of a device may or may not be congruent with their performance with the same device. An in-vehicle application, for example, may be perceived as adding safety when it may not (see, Andre and Wickens, 1995). Therefore, the principle of convergent empirical evidence from performance and preference is paramount. Conducting multiple studies on particular ITS application classes will require the coordinated efforts of a number of governments (e.g., EC, TC, FHWA).

The interpretation of the meaning of measures in terms such as safety or mobility requires a transformation from one measurement system to another where the transform has not been agreed upon or established. More specifically, a transform from a continuous ratio measure such as time to lane crossing to a categorical variable that determines the level of safety (e.g., safe, less safe, unsafe, etc.) is required. However, normative distributions for most tasks that comprise driving have not been determined yet. Individuals and groups of drivers may vary. Hence, the assignment of categories of safety based on driver performance cannot proceed. Nevertheless, the assignment of categories and agreement on the mapping between performance and relative safety will be a difficult but necessary political enterprise.

Usability engineering and related methods developed within the human-computer interaction community have the desirable properties of speed of conducting studies and a relatively low cost. These methods are ideally suited to points early within the development cycle of ITS applications. More formal methods which have been traditionally used within automotive ergonomics, such as on-road, test track, and driving simulation, allow interaction with ITS applications and driving to be assessed simultaneously. A range of experimental contexts from laboratory to on-road testing and evaluation are generally paired with the product's stage in the development cycle. Cost and the loss of control of experimental confounds tend to increase as evaluation methods become more and more like real operational traffic contexts. Ethical questions that surround placing drivers at risk when testing and evaluating ITS applications on a large scale have not been adequately addressed by researchers.

The manifestation of new error forms that may increase the likelihood that an accident could occur are exceedingly difficult to identify in conventional evaluation contexts, because experimental demand is likely to increase motivation and performance. Drivers have the capacity to adapt their looking behaviours depending on the relevancy of information to the goals of the driver. Thus, errors that may be evident at one point in an evaluation may disappear as the driver learns to use the device in an efficient manner. Conversely, drivers may not learn to look at an ITS technology when there is little traffic and insist on interacting with a device at intersections while trying to make complex decisions. Error methods are required that can *prospectively* identify potential errors and eliminate precursors in the design of a particular ITS application. The use of accident reconstruction methods to determine that a particular device precipitates particular kinds of errors after the product has entered the transportation system comes too late in the development cycle and expose corporations to tort liability.

VES. Two types of VES were examined in depth with regard to human factors evaluations that have been performed to date. Ultraviolet VES appear to be the most viable of the two. However, several critical parameters must be addressed before it can achieve wide-scale acceptance and use. UVB and UVC light must not reach the eyes of oncoming drivers if a headlamp is improperly filtered or broken. Headlamps must be tested and evaluated further to systematically determine the effects of glare—especially on older drivers. The edgeline, roadway markings, and hazards must be treated with florescent material. The durable reflective properties of the material in the presence of rain, ice, and snow must be determined. A number of standards should be revised to address UV headlamps prior to widescale market entry. When reflective material and headlamps begin to be used on a larger scale, a new problem arises. How will the expectancies of a driver with UVES interact with those of another who does not have the same headlamps? If one driver expects that the other can see further than he or she actually can, a false assumption error may occur (Treat, 1980). A number of test and evaluation, infrastructure, and assimilation issues lie ahead for those who will develop UVES.

For IVES, more obstacles to development are evident than for UVES. First, the field-of-view of the imaging system (i.e., HUD) will restrict the visibility of hazards or pedestrians that may appear in the periphery. Peripheral vision or useful-field-of-view declines with age is a logical candidate for support by a system that is able to enhance the detection of peripheral targets. However, projection of thermal images differences across the full windscreen is, at this time, cost prohibitive due to glass quality and projection system constraints. Second, images (of some colour) formed by a pedestrian resemble an undifferentiated blobs. These are difficult to recognize as a pedestrian and require perceptual learning and experience. Recognition difficulties will probably likely increase recognition and response times, which is contrary to improving perception-response times to hazards. Third, the image itself may cover up other important visual information in the traffic environment. Fourth, the alignment of the thermal image with the traffic environment may be imperfect because the eye location of the driver may vary intra- and inter-individually. Improper alignment of conformal imagery and the traffic environment place the pedestrian or other important thermal delineations in the wrong place. Transformations of visual-motor space to these slightly non-aligned positions would then be required of the driver. In combination, these four technical issues (among numerous others), do not necessarily place IVES in an ideal development position *at this time*.

In summary, the evaluation of VES requires that the following are considered: individuals who may have difficulty using in-vehicle displays (older drivers); the fit of a presentation modality to drivers' sensory capabilities (auditory, visual, and multimodal); limiting tasks that divide attention (e.g., braking and object recognition); optimizing the form that display images take (e.g., size, colour, location, etc.); and determining whether the systems can be "safely" operated in a wide range of traffic contexts (e.g., in an emergency). The use of VES may also produce new kinds of behaviours. It is unknown whether or not drivers will adopt higher speeds at night because they can see further ahead (a negative behaviour compensation) or whether or not older drivers will choose to travel at night where they have not before and perhaps should not.

Older Driver Countermeasures. The overall intervention context in which VES can be placed should be considered. While UVES and IVES will enhance roadway, pedestrian, and hazard visibility in the future, a substantive body of countermeasures has progressed in the past several decades. Those working within vehicle design and engineering, civil engineering, and traffic safety have proposed numerous countermeasures. Broadly, these interventions can be grouped into those primarily focusing on the road, the vehicle, or the driver. Figure 8.1 shows nominally grouped design suggestions for older drivers. The interventions that are listed were identified and assembled during the process of guideline review and development (see, Evans 1991; Hanowski et al., 1995; McCoy, 1991; Mortimer and Fell, 1989; NHTSA, 1989; OECD, 1990; TRB, 1988; Waller, 1985; and Yanik, 1991).

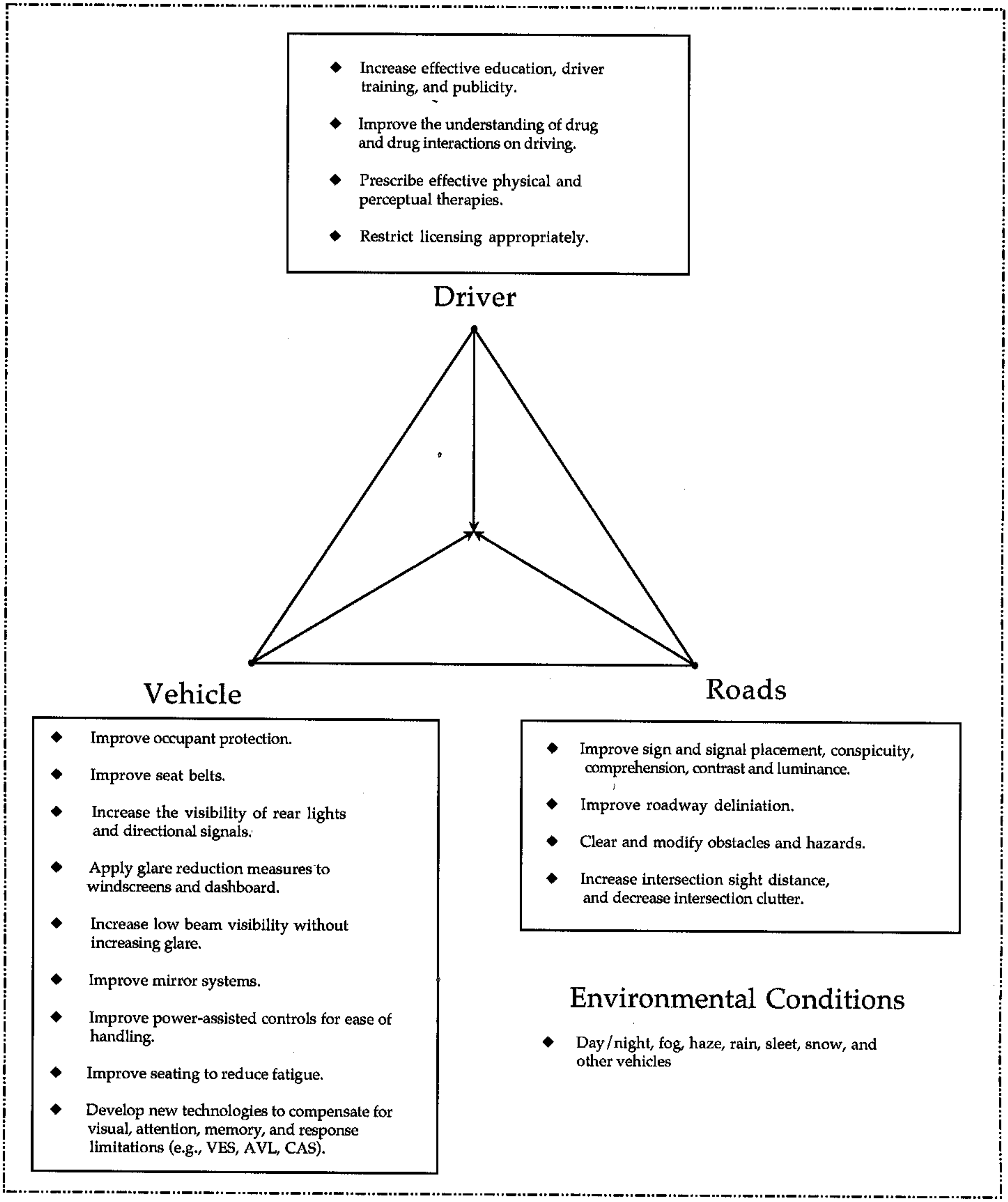

Figure 8.1. Older driver interventions and countermeasures. Recommendations culled from Evans (1991), Hanowski et al. (1995), McCoy (1991), Mortimer and Fell (1989), NHTSA (1989), OECD (1990), TRB (1988), Waller (1985), and Yanik (1991).

In the larger context of interventions, ITS applications represent a small unproven fraction of those countermeasures that are available. Some of the interventions, such those that appropriately restrict drivers' licenses, may have a net negative effect on mobility and have met with stiff political opposition. Most listed are neutral with respect to mobility (e.g., increase occupant protection) or positive (e.g., increase sight distance at intersections). A systematic review of the impact of each of these countermeasures on safety and mobility has not been performed (see, e.g., Evans, 1985). While numerous ITS applications have the potential to increase older driver mobility, many countermeasures have been developed in the past and many more are being researched for the future. Because the aging demographic shift requires it, many more driver, vehicle, and roadway solutions will be needed.

The consequences of a crash are more likely to kill an older driver or passenger. Thus, the focus of older driver interventions, if they are to be successful, is to concentrate on providing more or additional occupant protection (Eberhard, 1996; Evans, 1991; Hanowski et al., 1995). Other solutions have yet to be articulated. For example, Eberhard (1996, p. 35) rhetorically asks how to best assist the elderly to regulate their own driving. One way to achieve this goal is to create an ITS in-vehicle feedback device that informs the driver about various declines in their capability. Such a product could be installed so that the driver could determine the degree that they pose a risk to themselves and others. Suggestions for compensatory behaviours based on normative performance could also be integrated into the feedback from the device.

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APPENDIX A: IN-VEHICLE ITS DESIGN GUIDELINES

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